Final
Technical Support Document for
HWC MACT Standards

Volume IV:

Compliance with the HWC MACT Standards

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ABSTRACT

The U.S. Environmental Protection Agency (EPA) regulates the burning of hazardous waste in incinerators under 40 CFR Part 264/265, Subpart O and in boilers and industrial furnaces under 40 CFR Part 266, Subpart H. The Agency is promulgating revised regulations applicable to these hazardous waste combustion devices. This document provides technical background for the monitoring and operating requirements in the final rule.

The rule requires the use of continuous emissions monitors for carbon monoxide or hydrocarbons (and for oxygen to provide a dilution correction), and includes revised performance specifications for these monitors. In addition, the rule requires installation of continuous emissions monitors for particulate matter, but defers setting an effective date for the installation and use of particulate matter continuous emissions monitoring systems to a future rulemaking. A source can petition EPA for approval of the use of continuous emissions monitors as Alternative Monitoring Methods in lieu of operating parameter limits for other regulated hazardous air pollutants under §63.8 (f) of the General Provisions of MACT.

Compliance with emission limits for those pollutants that are not monitored directly at the stack will be achieved through the monitoring of certain system operating parameters that affect emissions levels (possibly in conjunction with indirect surrogate continuous monitoring). System operating parameters will be chosen which are indicative of the day-to-day operation and performance of the hazardous waste burner. This document includes procedures to adjust and control the operating parameter, procedures to measure and monitor the operating parameter, procedures to comply with the operating parameter limit (e.g., monitoring and averaging requirements), and procedures to set the operating parameter limit (e.g., based on comprehensive performance tests or equipment manufacturer and/or designer specifications).

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NOMENCLATURE

AC - alternating current
ACA - absolute calibration audit
ACM - actual cubic meter
AES - atomic emission spectroscopy
APCD - air pollution control device
APCS - air pollution control system
avg - average
AWFCO - automatic waste feed cutoff
BIF - boilers and industrial furnaces
BLDS - bag leak detector system
BTF - beyond the floor
CAA - Clean Air Act
CAAA - 1990 Clean Air Act Amendments
CAM - compliance assurance monitoring
CD - calibration drift
CE - calibration error
CEM - continuous emissions monitor
CEMS - continuous emissions monitoring system(s)
CFR - Code of Federal Regulations
CGA - cylinder gas audit
CIF - carbon impregnated filter
CK - cement kiln
CKRC - Cement Kiln Recycling Coalition
Cl_2 - chlorine, in its diatomic form
CMS - continuous monitoring system
CO - carbon monoxide
CoC - certification of compliance
COM - continuous opacity monitor
DC - direct current, District of Columbia
DL - detection limit
DOAS - differential optical absorption spectroscopy

DOC - documentation of compliance
DOD - Department of Defense
DOE - Department of Energy
DRE - destruction and removal efficiency
dscf - dry standard cubic foot
dscm - dry standard cubic meter
ECD - electron capture detector
EMC - Emissions Measurement Center
EPA - U.S. Environmental Protection Agency
ESC - Environmental Systems Corporation
ESP - electrostatic precipitator
F - Fahrenheit
FF - fabric filter
FID - flame ionization detector
FPD - flame photometric detector
FTIR - Fourier transform infrared
GC - Gas chromatograph
GCP - good combustion practice
GFC - gas filter correlation
gr - grain
HAP - hazardous air pollutant
HCl - hydrogen chloride
HC - hydrocarbons
HEPA - high energy particulate air
Hg - mercury
hr - hour
HRA - hourly rolling average
HWC - hazardous waste combustion, hazardous waste combustor
HWI - hazardous waste incinerator
ICAP - inductively coupled argon plasma
ICP - inductively coupled plasma
ID - induced draft
IMS - ion mobility spectroscopy
ISE - ion selective electrode
IWS - ionizing wet scrubber
kg - kilogram
KV - kilovolts
KVA - kilovolt-amperes

KS - Kansas
lb - pound
LED - light emitting diode
LIF - laser induced fluorescence
LVM - low-volatile metal(s)
LWAK - lightweight aggregate kiln
MACT - maximum achievable control technology
mg - milligram
Mg - megagram
MS - mass spectroscopy or spectrometer
MTEC - maximum theoretical emissions concentration
MWC - Municipal Waste Combustor
m^3 - cubic meters
M5 - Method 5
ng - nanogram
NDIR - non-dispersive infrared
NIC - notice of intent to comply
NIST - National Institute of Standards and Technology
NJ - New Jersey
NOC - notification of compliance
NODA - notice of data availability
NO_x - oxides of nitrogen
OSW - Office of Solid Waste
O_2 - diatomic oxygen
PAH - polycyclic aromatic hydrocarbons
PCB - polychlorinated biphenyl
PCDD - polychlorinated dibenzo-p-dioxins
PCDF - polychlorinated dibenzofurans
pH - a measure of acidity (the negative logarithm (base 10) of the hydronium ion concentration)
PIC - product of incomplete combustion
POHC - principal organic hazardous constituent
PM - particulate matter, afternoon
p/p - power to performance ratio
ppm - parts per million
ppmv - parts per million by volume
PS - performance specification
QA - quality assurance
RA - rolling average, relative accuracy

RATA - relative accuracy test audit
RCA - response correlation audit
RCRA - Resource Conservation and Recovery Act
RSD - relative standard deviation
SBIR - Small Business Innovative Research (grant)
SVM - semivolatile metal(s)
SVOC - semivolatile organic compound
SO_2 - sulfur dioxide
SRE - system removal efficiency
TEQ - toxic equivalent
THC - total hydrocarbons
TSCA - Toxic Substances Control Act
TÜV - Technischer Überwachungsverein
U.S. - United States
UV - ultraviolet
VOC - volatile organic compound
VOST - volatile organic sampling train
WESP - wet electrostatic precipitator
XRF - x-ray fluorescence
ZD - zero drift
µg - microgram

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CHAPTER 1

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is setting "Maximum Achievable Control Technology" (MACT) standards for hazardous waste combustors (HWCs): hazardous waste incinerators (HWIs), hazardous waste burning cement kilns (CKs), and hazardous waste burning lightweight aggregate kilns (LWAKs). The MACT emission standards are being developed under Title III of the 1990 Clean Air Act Amendments (CAA). MACT emissions standards are established for the following hazardous air pollutants (HAPs) from HWCs: polychlorinated dioxins and furans (PCDD/PCDF); mercury (Hg); semivolatile metals (SVM) which include cadmium (Cd) and lead (Pb); low volatile metals (LVM) which include arsenic (As), beryllium (Be), and chromium (Cr); hydrogen chloride and chlorine gas as total chlorine (HCl and Cl_2); particulate matter (PM) as a surrogate for the HAP metals of cobalt (Co), manganese (Mn), nickel (Ni), selenium (Se), and antimony (Sb); and carbon monoxide (CO) and hydrocarbons (HC) as surrogates for non-PCDD/PCDF organic HAPs.

This document provides technical background information for compliance with these regulations. It is the fourth in a series of five volumes of technical background documents for the revised rule. The others include:

- *Technical Support Document for HWC MACT Standards, Volume I: Description of Source Categories*, which contains process descriptions of each of the hazardous waste combustor source categories (incinerators, cement and lightweight aggregate kilns). Also included are discussions on air pollution control device design, operation, and performance characteristics of current systems, as well as state-of-the-art techniques that are applicable.

- *Technical Support Document for HWC MACT Standards, Volume II: HWC Emissions Database*, which contains a summary of the HWC emissions information on metal HAPs, particulate matter, HCl and Cl_2, hydrocarbons, carbon monoxide, semivolatile and volatile organic compounds, and PCDD/PCDF. Other information contained in the data summary include company name and location, emitting process information, combustor design and operation information, APCD design and operation information, stack conditions during testing, feedstream feed rates, and emissions rates of HAPs by test condition.

- *Technical Support Document for HWC MACT Standards, Volume III: Selection of MACT Standards and Technologies*, which discusses the approach and identifies the MACT Floors for each HAP and source category for existing sources and new sources.

- *Technical Support Document for HWC MACT Standards, Volume V: Engineering Costs*, which contains cost estimates and emissions reductions associated with the HWC MACT standards.

The emission standards have been developed through the MACT approach defined in Title 3 of the 1990 Clean Air Act Amendments (CAAA). In this approach the MACT floor standard for existing facilities is established at the level of the average performance of the best 12% of existing sources. Depending on the additional benefits and costs, EPA may elect to set more stringent, but technically achievable, BTF standards for specific HAPs. In the final rule, BTF standards have been set for PCDD/PCDF for incinerators with waste heat boilers, for SVM for CKs and LWAKs, and for total chlorine for LWAKs.

The floor and BTF standards have been selected based on a database (described in *Technical Support Document for HWC MACT Standards, Volume II: HWC Emissions Database*) of trial burn and compliance test emissions measurements from 105 incinerators, 31 cement kilns, and 16 lightweight aggregate kilns[1] using a process described in detail in *Technical Support Document for HWC MACT Standards, Volume III: Selection of MACT Standards and Technologies*. The database contains information from an additional 17 incinerators, 12 cement kilns, and 1 lightweight aggregate kiln which are no longer burning hazardous waste; however, data from these facilities were not used in setting the floor or BTF standards.

1.1 MACT STANDARDS AND MONITORING REQUIREMENTS

The subsequent sections of this document provide rationale for the various monitoring requirements set by the HWC MACT rule, and discuss how to set and comply with operating limits. Note that detailed descriptions of the combustion systems and their control equipment are provided in Volume I. MACT standards are listed in Table 1-1 through 1-3.

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[1]Note that some of these LWAKs share air pollution control equipment and are operated intermittently. The cost and emissions estimates described in Volume V have been developed only for the 10 LWAKs which can operate simultaneously.

1.2 CONTINUOUS EMISSIONS MONITORS

The new HWC MACT rule requires the use of continuous emissions monitoring systems (CEMS) for compliance with the CO and HC standards. No other continuous emissions monitors are required at this time. The rule also requires the installation of CEMS for particulate matter (PM), but does not specify an effective date for this requirement. EPA is in the process of gathering additional data to develop source-specific performance requirements for particulate matter CEMS and to resolve other outstanding technical issues. These issues include all questions related to implementation of the particulate matter CEM requirement, such as the relation of the PM CEMS requirement to all other testing, monitoring, notification, and record keeping; the relation of the particulate matter CEMS requirement to the PM emission standard; and technical issues involving performance, maintenance and correlation of the particulate matter CEM itself. These issues will be addressed in a subsequent rulemaking. Therefore, EPA has deferred the effective date of the PM-CEMS requirement pending further testing and additional rulemaking.

Owners and operators may petition the Administrator to use CEMS for compliance monitoring for Hg, SVM, LVM, HCl, and Cl_2 (as well as PM if PM CEMS are not ultimately required) under §63.1209(g) as “Alternative Monitoring Methods” in lieu of compliance with the corresponding operating parameter limits. For example, if a source were approved to use a continuous mercury emissions monitor to demonstrate compliance with the mercury standard, then many of the operating parameter limits for mercury may not need to be set or used for compliance while the CEMS is online.

1.3 ALTERNATIVE MONITORING METHODS

In response to the HWC MACT rule, as originally proposed, and to various subsequent Notices of Data Availability, EPA received numerous comments on why some aspects of the proposed rule were not possible, practical, or applicable to specific HWCs; and EPA received suggestions for better ways to demonstrate compliance with the MACT standards for some of those sources. Rather than attempting to address all of these issues in a single all-encompassing rule, the HWC MACT rule provides a mechanism for petitioning the regulatory authority for use of an alternative monitoring method. For standards monitored with a CEMS required by the rule (i.e., CO and HC), this can be done under the General Provisions of MACT (§63.8(f)). For standards other than those monitored with a CEMS required by the rule, this can be done under §63.1209(g). Note that authority for approving alternative monitoring petitions submitted under §63.8(f) (i.e., for alternatives to CO and HC monitoring) is reserved to the EPA; whereas, authority for approving alternative monitoring petitions submitted under 63.1209(g) (i.e., for alternatives to monitoring standards other than CO and HC) can be delegated to authorized states. The application for approval of an alternative monitoring method must include information justifying the request for an alternative monitoring system such as the technical or economic infeasibility or the impracticality of the required method for the affected source; a description of the proposed alternative monitoring system, including the operating parameter to be monitored, the monitoring approach/technique, the averaging period, and how the limit is to be calculated; and data or information documenting that the alternative monitoring requirement would provide equivalent or better assurance with the emissions standard, or that it provides the best assurance that is technically and economically practicable. In general, these requests should be submitted with the comprehensive performance test plan in order to facilitate coordinated testing.

1.4 REPORT ORGANIZATION

This document provides technical background for compliance with the HWC MACT rule. It includes this introduction and the following chapters with discussions on

- Chapter 2: How to determine operating parameter limits from comprehensive performance testing
- Chapter 3: Limits to control dioxins and furans
- Chapter 4: Limits to control particulate matter
- Chapter 5: Limits to control mercury
- Chapter 6: Limits to control toxic metals
- Chapter 7. Limits to control chlorine
- Chapter 8. Limits to control combustion system leaks
- Chapter 9. Limits to control non-dioxin organics
- Chapter 10. Limits to control destruction and removal efficiency
- Chapter 11. Automatic waste feed cutoff requirements
- Chapter 12. Continuous emissions monitoring
- Chapter 13. Special provisions
- Chapter 14. Operating and maintenance guidelines
- Chapter 15. Compliance schedule
- Chapter 16. Test methods
- Chapter 17. Revisions to the comparable fuel specification
- Appendix A. CEMS surveys
- Appendix B. Comparable fuels specification benchmark fuels analytical data
- Appendix C. Documentation of EPA discussions with TUV

TABLE 1-1. STANDARDS FOR EXISTING AND NEW INCINERATORS

Hazardous Air Pollutant or Hazardous Air Pollutant Surrogate	Emissions Standard[1]	
	Existing Sources	New Sources
Dioxin /Furan	0.20 ng TEQ[2]/dscm; or 0.40 ng TEQ/dscm and temperature at inlet to the initial dry particulate matter control device ≤ 400° F	0.20 ng TEQ/dscm
Mercury	130 µg/dscm	45 µg/dscm
Particulate Matter[3]	34 mg/dscm (0.015 gr/dscf)	34 mg/dscm (0.015 gr/dscf)
Semivolatile Metals	240 µg/dscm	24 µg/dscm
Low Volatile Metals	97 µg/dscm	97 µg/dscm
Hydrochloric Acid/Chlorine Gas	77 ppmv	21 ppmv
Hydrocarbons[4,5]	10 ppmv (or 100 ppmv carbon monoxide)	10 ppmv (or 100 ppmv carbon monoxide)
Destruction and Removal Efficiency	For existing and new sources, 99.99% for each principal organic hazardous constituent (POHC) designated. For sources burning hazardous wastes F020, F021, F022, F023, F026, or F027, 99.9999% for each POHC designated.	

1 All emission levels are corrected to 7 percent oxygen

2 Toxicity equivalent quotient, the international method of relating the toxicity of various dioxin/furan congeners to the toxicity of 2,3,7,8-TCDD.

3 An alternative PM standard of 68 mg/dscm (0.03 gr/dscf) applies to existing and new incinerators which have nondetectable levels of CAA metals (excluding mercury)

4 Hourly rolling average. Hydrocarbons reported as propane.

5 Incinerators that elect to continuously comply with the carbon monoxide standard must demonstrate compliance with the hydrocarbon standard of 10 ppmv during the comprehensive performance test.

TABLE 1-2. STANDARDS FOR EXISTING AND NEW CEMENT KILNS

Hazardous Air Pollutant or Hazardous Air Pollutant Surrogate	Emissions Standard[1]	
	Existing Sources	New Sources
Dioxin and Furan	0.20 ng TEQ/dscm; or 0.40 ng TEQ/dscm and control of flue gas temperature not to exceed 400°F at the inlet to the particulate matter control device	0.20 ng TEQ/dscm; or 0.40 ng TEQ/dscm and control of flue gas temperature not to exceed 400°F at the inlet to the particulate matter control device
Mercury	120 µg/dscm	56 µg/dscm
Particulate Matter[2]	0.15 kg/Mg dry feed and 20% opacity	0.15 kg/Mg dry feed and 20% opacity
Semivolatile Metals	240 µg/dscm	180 µg/dscm
Low Volatile Metals	56 µg/dscm	54 µg/dscm
Hydrochloric Acid and Chlorine Gas	130 ppmv	86 ppmv
Hydrocarbons: Kilns without By-pass[3, 6]	20 ppmv (or 100 ppmv carbon monoxide)[3]	Greenfield kilns: 20 ppmv (or 100 ppmv carbon monoxide and 50 ppmv[5] hydrocarbons) All others: 20 ppmv (or 100 ppmv carbon monoxide)[3]
Hydrocarbons: Kilns with By-pass; Main Stack[4, 6]	No main stack standard	50 ppmv[5]
Hydrocarbons: Kilns with By-pass; By-pass Duct and Stack[3, 4, 6]	10 ppmv (or 100 ppmv carbon monoxide)	10 ppmv (or 100 ppmv carbon monoxide)

Destruction and Removal Efficiency	For existing and new sources, 99.99% for each principal organic hazardous constituent (POHC) designated. For sources burning hazardous wastes F020, F021, F022, F023, F026, or F027, 99.9999% for each POHC designated.

[1] All emission levels are corrected to 7% O_2, dry basis.

[2] If there is an alkali by-pass stack associated with the kiln or in-line kiln raw mill, the combined particulate matter emissions from the kiln or in-line kiln raw mill and the alkali by-pass must be less than the particulate matter emissions standard.

[3] Cement kilns that elect to comply with the carbon monoxide standard must demonstrate compliance with the hydrocarbon standard during the comprehensive performance test.

[4] Measurement made in the by-pass sampling system of any kiln (e.g., alkali by-pass of a preheater and/or precalciner kiln; midkiln sampling system of a long kiln).

[5] Applicable only to newly-constructed cement kilns at greenfield sites. 50 ppmv standard is a 30-day block average limit. Hydrocarbons reported as propane.

[6] Hourly rolling average. Hydrocarbons are reported as propane.

TABLE 1-3. STANDARDS FOR EXISTING AND NEW LIGHTWEIGHT AGGREGATE KILNS

Hazardous Air Pollutant or Hazardous Air Pollutant Surrogate	Emissions Standard[1]	
	Existing Sources	New Sources
Dioxin/Furan	0.20 ng TEQ/dscm; or 0.40 ng TEQ/dscm and rapid quench of the flue gas at the exit of the kiln to less than 400°F	0.20 ng TEQ/dscm; or 0.40 ng TEQ/dscm and rapid quench of the flue gas at the exit of the kiln to less than 400°F
Mercury	47 µg/dscm	33 µg/dscm
Particulate Matter	57 mg/dscm (0.025 gr/dscf)	57 mg/dscm (0.025 gr/dscf)
Semivolatile Metals[2]	250 µg/dscm	43 µg/dscm
Low Volatile Metals[3]	110 µg/dscm	110 µg/dscm
Hydrochloric Acid/Chlorine Gas	230 ppmv	41 ppmv
Hydrocarbons[2, 3]	20 ppmv (or 100 ppmv carbon monoxide)	20 ppmv (or 100 ppmv carbon monoxide)
Destruction and Removal Efficiency	For existing and new sources, 99.99% for each principal organic hazardous constituent (POHC) designated. For sources burning hazardous wastes F020, F021, F022, F023, F026, or F027, 99.9999% for each POHC designated.	

1 All emission levels are corrected to 7% O_2, dry basis.

2 Hourly rolling average. Hydrocarbons are reported as propane.

3 Lightweight aggregate kilns that elect to continuously comply with the carbon monoxide standard must demonstrate compliance with the hydrocarbon standard of 20 ppmv during the comprehensive performance test.

CHAPTER 2

HOW TO DETERMINE AND COMPLY WITH OPERATING PARAMETER LIMITS

Operating parameter limits are set based on conditions demonstrated during comprehensive performance testing, based on equipment manufacturer and/or designer recommended specifications, or at a specified value (e.g., an ambient pressure combustion chamber pressure limit) . Depending on the parameter, compliance with these limits are on an instantaneous basis, or on a rolling average basis.

2.1 RATIONALE FOR AVERAGING PERIODS FOR PARAMETERS SET FROM THE COMPREHENSIVE PERFORMANCE TEST

As discussed in *Technical Support Document for HWC MACT Standards, Volume III: Selection of MACT Standards and Technologies*, emissions standards have been established based on emissions data averaged over all the runs (typically three) of a single condition of a trial burn or compliance test. The comprehensive performance test demonstrates compliance with these emissions standards over a similar period and establishes operating limits which reasonably assure that emissions will not exceed those demonstrated in the performance test for the duration of the performance test and for any given period corresponding to that duration thereafter. Averaging periods have been chosen for various compliance parameters to reasonably assure compliance with the emissions standards for the duration equivalent to three runs of the performance test. For those parameters which are linearly related to emissions (i.e., feedrates of metals, chlorine, and incinerator ash), a 12-hour averaging period has been chosen because it is the upper bound of the combined duration of a typical metals/chlorine emissions test. For other parameters which are not linearly related to emissions, a shorter averaging period better assures compliance with the emission standards. Shorter averaging periods can help to prevent a source from offsetting above-average operating parameter peaks that lead to disproportionately high emissions spikes with periods of below-average operating parameter levels. Such operations can lead to long term average operating parameter values that reflect the average values demonstrated in the performance test, but, because of the nonlinear relationship, can also result in HAP emissions that exceed levels demonstrated in the performance test (for equivalent time periods). See Section 2.2.2 for specific examples that explain why shorter averaging periods better assure compliance with the emission standards.

A one-hour averaging period has been chosen for these nonlinear parameters. The parameters are easily controllable within a one-hour time frame (see discussion in section 2.2.2) and this period will, in most instances, provide adequate assurance that emissions will not exceed those demonstrated in the comprehensive performance test.

The Agency considered requiring 10-minute averaging periods rather than one-hour averaging periods for most nonlinear parameters, but concluded that it is not appropriate to require ten-minute averaging periods on a national basis. The Agency's ability to assess the potential benefit of requiring ten-minute averaging periods for all hazardous waste combustors affected by this final rule is limited significantly by the paucity of short-term, minute-by-minute, operating parameter data. Without these data the Agency cannot effectively evaluate whether operating parameter excursions occur to an extent that warrant national ten-minute averaging period requirements for all hazardous waste combustors. Nevertheless, a 10-minute averaging period, or perhaps instantaneous limits, may be more appropriate for some parameters at some sites. In such a situation, the Administrator has the authority under 63.1209(g)(2) to specify additional or alternative requirements (including shorter averaging periods) on a case-by-case basis. See Section 2.2.2 for a brief discussion on the factors a regulatory official may consider when determining whether averaging periods less than one-hour in duration may be warranted.

In cases where 10-minute averaging periods are imposed, the permit writer may consider giving sources the option of complying with a single 10-minute limit set based on the average conditions demonstrated in the comprehensive performance test, or of complying with dual limits: a 10-minute limit based on the extreme conditions demonstrated in the comprehensive performance test and a 1-hour limit based on the average conditions demonstrated in the comprehensive performance test. A similar approach was proposed in the April 1996 NPRM, bit, as discussed above, was not adopted for HWCs on a national basis. See 61 FR AT 17417.

2.2 SETTING AND COMPLYING WITH OPERATING LIMITS

The procedure to determine operating parameter limits which are based on comprehensive performance testing depends on the operating parameter. Note that in the below discussions describing the use of comprehensive performance test data to set operating limits, data are to be considered from all runs of a test condition in compliance with the emissions limits, regardless of whether or not the individual runs are in compliance.

2.2.1 Instantaneous Limits

An instantaneous limit is required only for combustion chamber pressure to control combustion system leaks. This is because any perturbation above the limit may result in uncontrolled emissions exceeding the standard.

The instantaneous combustion chamber pressure limit is not set from the comprehensive performance test; rather, unless the system is totally enclosed or an alternative approach is approved by the Administrator, an AWFCO is required any time the combustion chamber pressure instantaneously goes above ambient pressure.

For compliance with the combustion chamber pressure limit, measurements are made continuously without integration, and no averaging period is allowed. Unlike averaged parameters, which must be sampled a minimum of once-every-15-seconds, pressure monitors must detect and record constantly without interruption. Note that differential pressure transducers (typically used to measure combustion chamber pressure) are capable of providing a continuous electronic signal with response times down to 10 milliseconds.

2.2.2 Rolling Average Limits

A rolling average for a particular monitored parameter is calculated as the average of all one-minute averages for that parameter ending at the last minute, and stretching back over the duration of the averaging period. For example, a one-hour rolling average is the average of 60 consecutive one-minute averages. It is updated every minute by including the latest one-minute average and dropping the one-minute average from one hour ago.

A one-minute average is the average of the data over a sixty second period, with data processed at least once every 15 seconds. This is the same as the approach used in the BIF rule (U.S. EPA, 1992).

Note that upon initial compliance (i.e., on the compliance date or at initial startup), a rolling average does not begin until a sufficient number of one-minute averages have been recorded to calculate the rolling average (i.e., 12-hours worth for a 12-hour rolling average, and 60-minutes worth for a one-hour rolling average).

If a rolling average is interrupted (i.e., when one-minute average values for a parameter are not recorded), data for that period are not counted and the rolling average is resumed when the system comes back online. For example:

- If a monitor goes offline for calibration at 2:00 PM and comes back online at 2:10 PM, the hourly rolling average at 2:20 PM would include data from the 50 minutes between 1:10 and 2:00 and the 10 minutes between 2:10 and 2:20; but it would not include the data for the period from 2:00 to 2:10 when the instrument was offline.

- If a source totally shuts down (i.e., no combustion occurs) for yearly maintenance for a three week period, the first one-minute average value recorded for the parameter for the first minute of renewed operations is added to the last 59-one minute averages before the source shutdown.

Note that this approach does not apply to time periods after the source initiates an AWFCO due to an exceedance of an operating parameter limit (OPL). After an AWFCO, a source must continue to monitor OPLs, and must continue to calculate rolling averages unless it operates under nonhazardous waste MACT requirements pursuant to the provisions found in 1206(b)(1)(ii).

If the source stops burning hazardous waste and if hazardous waste no longer remains in the combustion chamber, the source may elect to comply with the nonhazardous waste MACT requirements in lieu of the HWC MACT requirements pursuant to the provisions in 1206(b)(1)(ii). In this situation, a source is not required to continue to record compliance parameter values for purposes of HWC MACT compliance. Before hazardous waste burning is reinitiated, a source must document in the operating record when it elects to begin complying with the HWC requirements, and must again monitor and record compliance parameter values and rolling averages (as described above) neglecting data from the period when the source operated pursuant to 1206(b)(1)(ii). A source must not resume burning hazardous waste until all operating parameters are in compliance with its limits.

12-hour rolling average -- The rule requires 12-hour rolling average limits for the feedrate of mercury, semivolatile metals, low-volatile metals, chlorine, and ash (for incinerators) because feedrate and emissions are, for the most part, linearly related. In addition, a 12-hr rolling average limit is established for the maximum solids content of the scrubber liquid water when monitored with a continuous monitoring system because particulate matter emissions are expected to be linearly related to the solids concentration in the scrubber water. The twelve-hour period was chosen because it is the upper bound of the combined duration of three runs of a typical metals/chlorine emissions test. Tables 2-1 and 2-2 show sample times used for metals and chlorine trains for trial burns and compliance tests taken from the HWC Emissions Data Base. Thus, the 12-hour compliance averaging period for feedrate-related parameters is consistent with the period over which compliance with the emissions standards are demonstrated in the performance test.

12-hour rolling average limits are determined as the average of the average for each comprehensive performance test run. The average for each run is calculated as the sum of the one-minute averages divided by the number of one-minute averages taken in the run.

One-hour rolling average -- One-hour rolling average limits are required for all other parameters. The shorter averaging period is required for these parameters because:

1) There is a nonlinear relationship between HAP emissions and the limited operating parameter such that short term excursions may result in emissions spikes which are not balanced out by proportionally lower emissions when the operating parameter returns to levels which will result in compliance on a long-term average basis; or
2) The operating parameter is indicative of rapid, unrecoverable deterioration of the process effectiveness, thus quick control response is required to assure compliance with the emissions standards.

One-hour rolling average parameters can be classified into five groups:

- Group 1:
  - Group 1A
    - Minimum carbon feedrate to a carbon injection system
    - Minimum inhibitor feedrate to a dioxin/furan inhibitor injection system
    - Minimum sorbent feedrate to a dry scrubber
    - Minimum power input to ESP or IWS
    - Minimum pressure drop across a high energy scrubber
    - Minimum scrubber liquid flowrate and maximum flue gas flowrate, or minimum scrubber liquid/gas ratio
  - Group 1B
    - Minimum carrier fluid flowrate or nozzle pressure drop
    - Minimum fabric filter pressure drop
    - Minimum pressure drop across a low energy scrubber
    - Minimum liquid feed pressure to low energy wet scrubber
- Group 2
  - Maximum temperature at the inlet to a dry particulate matte control device, (Maximum temperature exiting the kiln for lightweight aggregate kilns)
- Group 3
  - Minimum gas temperature at inlet to a catalytic oxidizer
  - Minimum gas temperature for each combustion chamber

- Maximum gas temperature at inlet or exit of carbon bed
- Minimum pH of scrubber liquid

• Group 4
  - Maximum catalytic oxidizer temperature
• Group 5
  - Maximum hazardous waste feedrate
  - Maximum flue gas flowrate (or surrogate)

Note that hazardous waste firing system parameters, for which limits are identified and established on a site-specific basis, typically fall into Groups 1 or 3.

The general relationship between the Group 1 operating parameters and corresponding HAP emissions levels (and HAP control efficiency) is shown in Figure 2-1. At one extreme of operation, the device is effectively not being used (the operating parameter reads "zero"), and no control is being achieved -- for example, no sorbent is injected, ESP has no input power, etc.. Emissions are at an "uncontrolled" level. As the device begins to function, the operating parameter increases and HAP emissions are reduced at a fairly rapid rate. However, as the parameter continues to "improve", corresponding HAP emissions reductions decrease at a much slower rate and approach some limiting maximum degree of control (corresponding to a minimum achievable HAP emissions level). The relationship between these operating parameters and HAP emissions is clearly not linear (although it may approach linearity over a small range of operating parameter levels, for example at the lower or higher ends of the curve).

Group 1 parameters are further subdivided into Group 1A and Group 1B. Limits for Group 1A parameters are set from the comprehensive performance test. For example, consider the case illustrated in Figure 2-2 where during the performance test, sorbent is fed at a steady stoichiometric ratio of 3, with a chlorine system removal efficiency (SRE) of 90%. During subsequent operations, sorbent is fed at a stoichiometric ratio of 2 (with SRE of 70%) and 4 (with SRE of 93%) during equal 6-hour periods, with a resulting average SR of 3. The average SRE during this 12-hour period is 81.5% which is much lower than that during the performance testing. Resulting emissions would be almost twice as high as that during the performance testing, assuming a similar uncontrolled chlorine loading to the dry scrubber. One-hour averages would better assure that a source does not cycle its sorbent feedrate above and below the average levels demonstrated in the performance test such that chlorine emissions during normal operations would be higher than those demonstrated during the performance test.

Power input to an ESP is another example of a Group 1 parameter. A typical relationship between electrostatic precipitator (ESP) power input and particulate matter control efficiency is shown in Figure 2-3 (EPA, U.S.EPA). Theory and experimental testing indicate that ESP performance efficiency is exponentially related to ESP power. Consider a case where, during the performance test, a source operates its ESP at a steady 300 W/kacfm with an uncontrolled inlet PM loading of 40 gr/dscf. This results in a particulate matter collection efficiency of 99.93% and a PM emissions level of 0.03 gr/dscf. A source could document compliance during subsequent operations by cycling its ESP power above and below 300 W/kacfm (while maintaining a constant gas flowrate). If a source operates half the time at 250 W/kacfm and half the time at 350 W/kacfm, its average PM emissions would be approximately 0.05 gr/dscf (assuming the same ESP inlet particulate loading), which is well above the emission standard (for cement kilns). One-hour limits would better assure that a source could not cycle its ESP power above and below the average levels demonstrated in the performance test such that PM emissions during normal operations would be higher than those demonstrated during the performance test.

Pressure drop across a high-energy wet scrubber provides still another example of a Group 1 parameter. The typical nonlinear relationship between venturi scrubber pressure drop and scrubber performance efficiency for particulate matter is shown in Figure 2-4 (EER, 1990; EPA, 1991). Particulate matter capture efficiency is known to be exponentially related to pressure drop for a given particle size. Consider a case where, during the performance test, a particulate matter level of 0.03 gr/dscf is achieved at a pressure drop of 37 inches H_2O (based on an uncontrolled inlet of 0.3 gr/dscf, and a scrubber capture performance of 90%). During subsequent operations, however, the source cycles at pressure drops of 30 in. water (removal efficiency of 83%) and 45 in. water (removal efficiency 94%) during equal 6-hour time periods to maintain compliance on an 12-hour basis. The resulting average particulate matter emissions over this time period is 0.035 gr/dscf, which is about 20% higher than that during the performance testing. One-hour averages would better assure that a source does not cycle its pressure drop above and below the average levels demonstrated in the performance test such that emissions during normal operations would be higher than those demonstrated during the performance test.

Limits for Group 1B parameters are set based on manufacturer specifications. They are not set from the performance test because:

- Emissions are not typically very sensitive to the values of these parameters within the normal operating range;
- It is difficult to control these parameters sufficiently to allow maximizing/minimizing them in a comprehensive performance test; and/or
- They may conflict with other, more important parameters making it difficult to simultaneously maximize/minimize all parameters in the same comprehensive performance test.

The Group 2 parameter, dry APCD temperature, is a nonlinear indicator for PCDD/PCDF control. As discussed in Chapter 3, research testing has shown that PCDD/PCDF emission rate increases exponentially by roughly an order of magnitude for every 150°F increase in APCD temperature. Consider an example facility which takes extraordinary measures to operate a rock-steady performance test. The APCD temperature for the entire performance test is constant and the dioxin emissions in the performance test are exactly at the standard. In normal operation with a single 12-hour rolling average limit, the facility could conceivably cycle its instantaneous APCD temperature to equal extremes above and below the 12-hour rolling average limit for 6 hours at a time and still comply with the 12-hour rolling average limit. Because of the nonlinear nature of the relationship between APCD temperature and dioxin emissions, the higher emissions at the high temperature extreme are not entirely offset by lower emissions at the lower temperature extreme. If dioxin emissions for this facility increase an order of magnitude for every 150°F (as discussed above), emissions at 25 degrees above the 12-hour rolling average limit would result in dioxin emissions 47% above the standard and emissions at 25 degrees below the 12-hour rolling average limit would result in dioxin emissions 32% below the standard. If the facility spent half the time 25 degrees above the limit and half the time 25 degrees below the limit, the average emissions would be 7% above the standard. Similarly if the facility's instantaneous APCD temperature cycled 50 degrees above and below the 12-hour rolling average limit, the average dioxin emissions would be 31% above the standard, and if the facility's instantaneous APCD temperature cycled 75 degrees above and below the 12-hour rolling average limit, the average dioxin emissions would be 74% above the standard. Although a similar scenario could theoretically be envisioned for a facility complying with a 1-hour rolling average limit, it would require the facility to complete the up-and-down cycle much faster (i.e., once an hour), which is less likely to occur. Thus, one-hour limits in such a case better assure compliance with the emission standard than do 12-hour limits.

Consider another example facility for which an APCD temperature of 400°F corresponds to dioxin/furan emissions at the standard. To be safe, this facility typically operates 10°F below the limit, at 390°F and emits dioxin/furans at 86% of the standard. This facility could have a 150°F spike for 30 minutes up to 540°F and still keep its 12-hour rolling average temperature at about 396°F (a safe 4°F below the hourly rolling average limit). Its dioxin/furan emission rate for that 30-minute spike would increase by an order of magnitude and its 12-hour rolling average dioxin/furan emission rate would be 18% above the standard. If that facility had to comply with a 1-hour rolling average temperature limit, it could only have a 12.5°F temperature spike for 30 minutes up to 402.5°F and still keep its 1-hour rolling average temperature at about 396°F (a safe 4°F below the rolling average limit). Its dioxin/furan emission rate for those 30 minutes would increase by about 20% and its 1-hour rolling average dioxin/furan emission rate would still be only 95% of the standard. Thus, because of the nonlinear (in this case exponential) nature of the dependence of dioxin/furan emissions on APCD temperature, a facility limited by a 12-hour rolling average temperature could theoretically operate with one large temperature spike in a 12-hour period and emit dioxin/furan above the limit; whereas, if it were limited by a 1-hour rolling average, it could operate with one lesser temperature spike every hour and remain below the limit. A one-hour rolling average is more protective and better assures compliance with the emission standard..

For Group 3 parameters, there is a threshold beyond which HAP emissions increase significantly. For combustion temperature, combustion related PIC emissions are not proportionally related to combustion temperature. More likely, as temperature decreases below some threshold lower limit, combustion becomes unstable and emissions increase dramatically. A one-hour averaging period is thus needed to better assure compliance with the standard.

The typical relationship between principal organic hazardous waste constituent (POHC) combustion efficiency and combustion temperature is shown in Figure 2-5 (Dellinger et al., 1984). Chemical kinetics and experimental work indicate that destruction and removal efficiency (DRE) is a sensitive exponential function of temperature. Consider a case where, during the performance test, a DRE of 99.995% is achieved at an operating temperature of 1835°F. Assuming during subsequent operations, the facility cycles at temperatures of 1745°F (DRE of 99.95%) and 1925°F (DRE of 99.9995%) during equal 6-hour time periods to maintain compliance on a 12-hour basis (with swings of about 90°F). The resulting average DRE over this time period is essentially 99.97% (dominated by the poor performance at the lower temperature), which is worse than that demonstrated in the performance test (this assumes a constant feed of POHC during subsequent operations). Whereas at first glance this difference in DRE appears to be minor, it actually results in significant increases in organic HAP emissions. For example, if chlorobenzene was being fed to a combustor at a feedrate of 1000 lbs/day, an average DRE of 99.995% would result in a mass emission rate of chlorobenzene of 0.05 lbs/day. If the source instead achieves an average 99.97 DRE, the resultant chlorobenzene emissions would be approximately 0.3 lbs/day, or higher by a factor of six. One-hour averages would make it less likely that a source could cycle its temperature above and below the average levels demonstrated in the performance test such that organic HAP emissions during normal operations would be higher than those demonstrated during the performance test.

Similarly, a 1-hour averaging period is appropriate for minimum catalytic oxidizer operating temperature because if the catalytic oxidizer goes below a threshold temperature it can no longer support the PIC destruction reactions and PIC emissions increase dramatically.

High temperature spikes have the potential to release large amounts of organics and volatile metals that have been captured in the carbon bed over its operational lifetime. Thus, it may be especially important to control flue gas and bed temperatures on a short term basis to ensure that prolonged high temperature spikes due not occur. The final rule specifies that this parameter be limited on a 1-hour rolling average basis; however, it may be appropriate, on a site-specific basis, to set a conservative upper temperature limit to be complied with on a 10-minute rolling average basis, or on an instantaneous basis, if the design or operating history suggests that significant temperature swings might occur.

For Group 4 parameters, the limit is based on manufacturer specifications and is designed to prevent damaging the equipment. For example, if a catalytic oxidizer gets too hot, the catalyst may be damaged and it may no longer be as effective at oxidizing organic HAPs. Since such damage can occur quickly, a 1-hour averaging period is appropriate to prevent catalyst damage and to assure subsequent compliance with the standard.

Group 5 parameters (maximum hazardous waste feedrate and maximum flue gas flowrate), although they have a nonlinear effect on HAP emissions, are considered of secondary importance because there are other, more direct, indicators/controls on HAP emissions. Each can have a nonlinear effect on DRE and on emissions of organic HAPs. As the waste feedrate increases beyond the threshold which consumes all available oxygen, emissions of organic HAPs can go from levels of essentially zero to levels of significant concern. Similarly, flue gas flowrate increases can affect flame stability and gas phase residence time in ways that can have a nonlinear effect on HAP emissions. Thus, it is appropriate to set limits on these parameters on a 1-hour rolling average basis. However, since there are other parameters, such as combustion chamber temperature and CO and/or HC, which serve as more important controls and indicators of organic HAP emissions, it is appropriate to set 1-hour rolling average limits on these Group 5 parameters less stringently, based on maximum rather than average values demonstrated in the comprehensive performance test.

The operating parameters subject to 1-hour rolling average limits, as listed in the above five groups, are all easily controlled on a 1-hour basis. Measurement and control systems are available with adequate sensitivity and response time to make these averaging periods achievable. Table 2-3 lists examples of measurement and control systems for each 1-hour parameter. The response times of the measurement techniques listed in the table are all fast (i.e., well under one hour). Most of the control techniques (e.g., those relying on screw feeders, control valves, or voltage controllers) have response times well under one hour. Others with slower control system response times include:

- Minium pressure drop across a fabric filter. Although the response time for the typical control techniques (changing the filter cleaning frequency or bag maintenance/replacement) is slow, because this parameter is set based on manufacturer specifications (rather than on performance test conditions), the pressure drop in normal operation is expected to be comfortably above the limit, so fast control is not needed. The 1-hour average limit is needed to guard against sudden decreases in the pressure drop (as might result from a torn bag) which could result in sudden increases in emissions of metals and particulate matter.

- Minimum pressure drop across a low energy wet scrubber, for which the limit is based on manufacturer specifications. A fast way of controlling this parameter is to increase the flue gas flowrate by increasing the fuel/waste/air input to the system; however, this may conflict with limits on the maximum flue gas flowrate. Although the response time for the control technique listed in the table (shut down for maintenance) is slow, because this parameter is set based on manufacturer specifications (rather than on performance test conditions), the pressure drop in normal operation is expected to be comfortably above the limit, so fast control is not needed. The 1-hour average limit is needed to guard against sudden decreases in the pressure drop (as might result from maldistribution of the scrubber liquid) which could result in sudden increases in emissions of HCl and chorine.
- Scrubber liquid pH. Although the control technique (adding caustic to the scrubber water) is typically slow, pH changes slowly, so it is easy to predict when additional caustic will be needed and take action well in advance to prevent exceeding the 1-hour average limit.
- Minimum pressure drop across a high-energy scrubber. An automatically-controlled variable-throat high-energy scrubber should have no difficulty responding quickly enough to meet a one-hour rolling average for this parameter; however, a one-hour averaging period may be difficult to meet for scrubbers with non-automated variable throats. Facilities having scrubbers with fixed throats may find this parameter in conflict with the limit on the maximum flue gas flowrate. In situations where a 1-hour averaging period is not achievable for a specific parameter, a facility may need to petition the Administrator for use of an alternative monitoring method under §63.1209(g)(1)

Hourly rolling averages for the following parameters (i.e., those from Groups 1A, 2, and 3) are calculated by averaging the average operating parameter level for each performance test run.

- Maximum temperature at the inlet to a dry particulate matte control device, (Maximum temperature exiting the kiln for lightweight aggregate kilns)
- Minimum gas temperature for each combustion chamber
- Minimum carbon feedrate to a carbon injection system
- Minimum inhibitor feedrate to a dioxin/furan inhibitor injection system
- Minimum sorbent feedrate to a dry scrubber
- Maximum gas temperature at inlet or exit of carbon bed

- Minimum gas temperature at inlet to a catalytic oxidizer
- Minimum pressure drop across a high energy scrubber
- Minimum pH of scrubber liquid
- Minimum scrubber liquid flowrate and maximum flue gas flowrate (for chlorine control) or minimum scrubber liquid/gas ratio
- Minimum power input to ESP or IWS

The average for each run is calculated as the sum of the one-minute averages divided by the number of one-minute averages taken in the run.

Hourly rolling averages for maximum hazardous waste feedrate and maximum flue gas flowrate (for particulate matter, SVM, LVM, and DRE control) (i.e., Group 5 parameters) are calculated by averaging the highest hourly rolling averages for each performance test run.

Hourly rolling averages for the following parameters (i.e., those from Groups 1B and 4) are set based on manufacturer specifications:

- Minimum carrier fluid flowrate or nozzle pressure drop
- Minimum fabric filter pressure drop
- Minimum pressure drop across a low energy scrubber
- Minimum liquid feed pressure to low energy wet scrubber
- Maximum catalytic oxidizer temperature

Factors that may warrant 10-minute rolling averages or instantaneous limits -- As discussed above, the final rule does not require any parameters to be limited on a 10-minute rolling average basis. However, 63.1209(g)(2) allows the Administrator to impose shorter-than-1-hour averaging periods, if warranted, on a case-by-case basis. The arguments provided above to justify 1-hour rolling averages could be extended, on a site specific basis, to justify requiring 10-minute rolling averages or instantaneous limits.

Ten-minute rolling averages or instantaneous limits may be justified in site-specific situations where:

- Large variations in values for specific operating parameters are expected based on:
  - Previous operating parameter compliance history
  - The design of the facility
  - Experience with similar facilities; or
- The facility has a history of exceeding emission standards.

These considerations become more important for operating parameters established in compliance tests where the demonstrated emissions of associated HAPs or HAP surrogates are close to the emissions standards.

TABLE 2-1. EXAMPLES OF CHLORINE AND METAL SAMPLING DURATIONS FOR INCINERATORS

	Incinerators			
	Chlorine		Metals	
Condition	Sample Time (hr)	Sample Vol. (dscf)	Sample Time (hr)	Sample Vol. (dscf)
331C2	1	44		
331C3	1	44		
713C1	1	35		
808C1	2	75		
808C2	2	70		
357C1	3.5	100		
477C1	3	81		
700C1	2	71		
700C2	2	71		
806C1	1.5	45		
500C1	3	88		
500C2	2	60		
500C3	3	88		
504C1	1	42	2	84
347C1	1.3	36	2.7	74
340C1	2	81	2	81
340C2	2	82	2	82
459C1	1	32		
454C1	1.7	81		
605C1	1	30	1	30
209C1	2	81	2	85
209C2	2	70	2	69

TABLE 2-2. EXAMPLES OF CHLORINE AND METAL SAMPLING DURATIONS FOR CEMENT KILNS AND LIGHTWEIGHT AGGREGATE KILNS

	Cement Kilns			
	Chlorine		Metals	
Condition	Sample Time (hr)	Sample Vol. (dscf)	Sample Time (hr)	Sample Vol. (dscf)
318C1	2	68	2	70
309C1	1	50	2	92
320C1	2	60	4	111
321C1	7	200	7.2	221
335C6	2	84	2	83
203C4	1.4	65	1.4	65
203C5	1	32	2	65
203C6	1	47		
200C4	2	77	2	71
200C5	2	76	2	70
200C6	2	67	2	59
204C1			2	75
302C1	4	85	4	80
302C4	3.5	87	3.5	95
304C1			2	45
308	1.5	45		
481	2	76	2	94
315C1	2	99	2	100
315C2	2	98	2	97
303C1	2	66	2	68
608C1	2	94	1	45
680C1	2	63	1.8	59
	LWAKS			
	Chlorine		Metals	
Condition	Sample Time (hr)	Sample Vol. (dscf)	Sample Time (hr)	Sample Vol. (dscf)
225C1	2	100	1	51
223C1	2	70	1	34
226C1	2	86	1	43
224C1	2	80	2	80

TABLE 2-3. MEASUREMENT AND CONTROL SYSTEMS FOR 1-HOUR PARAMETERS

Parameter	Example Measurement Technique	Example Control Technique
Carbon/Inhibitor/Sorbent Injection Rate	Scale/Timer	Screw Feeder RPM
Carrier Fluid Flowrate	Orifice Meter	Control Valve on Carrier Fluid
Fabric Filter Pressure Drop	Pressure Transducer	Bag Cleaning Frequency, Bag Maintenance/Replacement
ESP or IWS Power Input	Voltage-Current Meter	Voltage Controller
High-Energy Wet Scrubber Pressure Drop	Pressure Transducer	Change Area of Variable Throat
Low Energy Wet Scrubber Pressure Drop	Pressure Transducer	Shut Down for Maintenance (e.g., repair/replace packing)
Liquid Feed Pressure to Low Energy Wet Scrubber	Pressure Transducer	Control Valve on Scrubber Liquid
Wet Scrubber Liquid Feedrate or Liquid to Gas Ratio	Orifice Meter	Control Valve on Scrubber Liquid
Temperature at Inlet to Dry Particulate Matter Control Device or Lightweight Aggregate Kilns, Temperature Exiting Kiln	Thermocouple	Control Valve on Quench Water or Fuel
Catalytic Oxidizer Temperature	Thermocouple	Control Valve on Fuel or Quench Water
Combustion Chamber Temperature	Thermocouple	Control Valve on Fuel
Carbon Bed Temperature	Thermocouple	Control Valve on Fuel or Quench Water
Scrubber Liquid pH	pH meter	Add Caustic
Hazardous Waste Feedrate	Scale/Timer or Liquid Flow Meter	Solids Charge Rate or Valve on Liquid Waste
Flue Gas Flowrate	Pitot/Pressure Transducer	Fuel/Air Feedrate

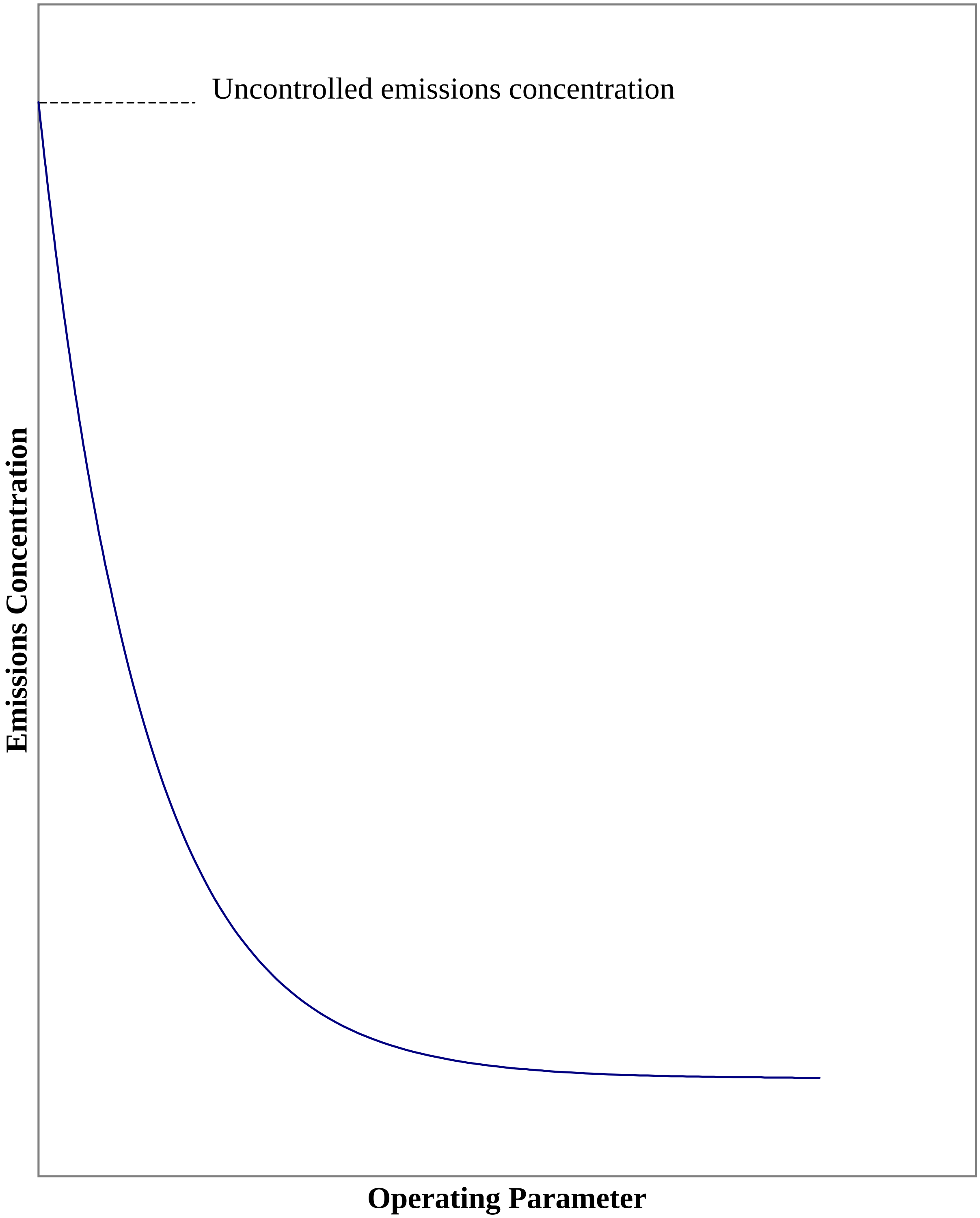


Figure 2-1. Typical relationship between Group 1 operating parameter and emissions concentration of controlled HAP.

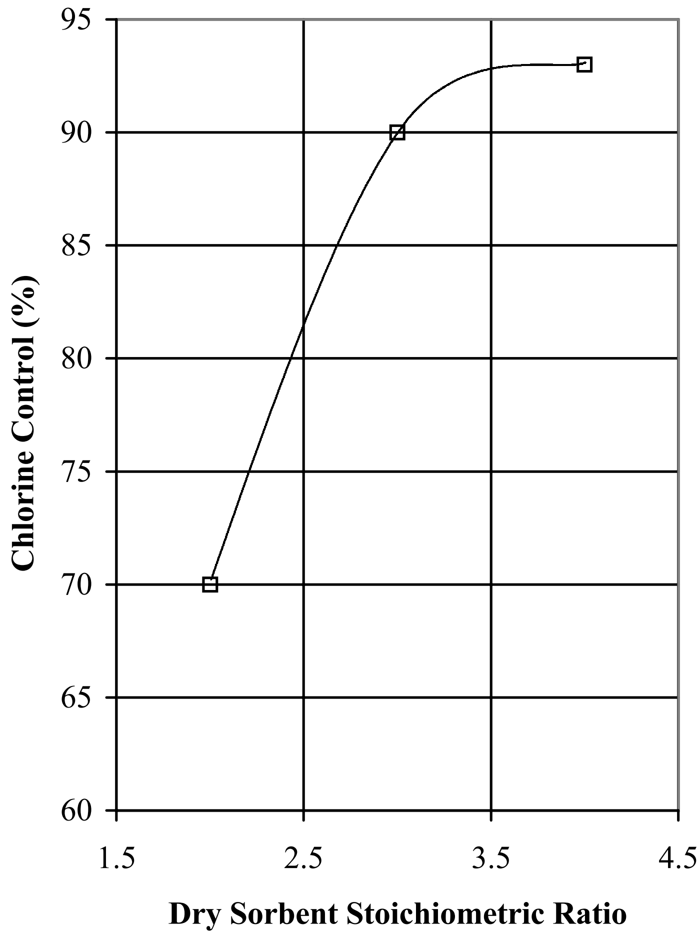


Figure 2-2. Chlorine control as a function of dry sorbent stoichiometric ratio.

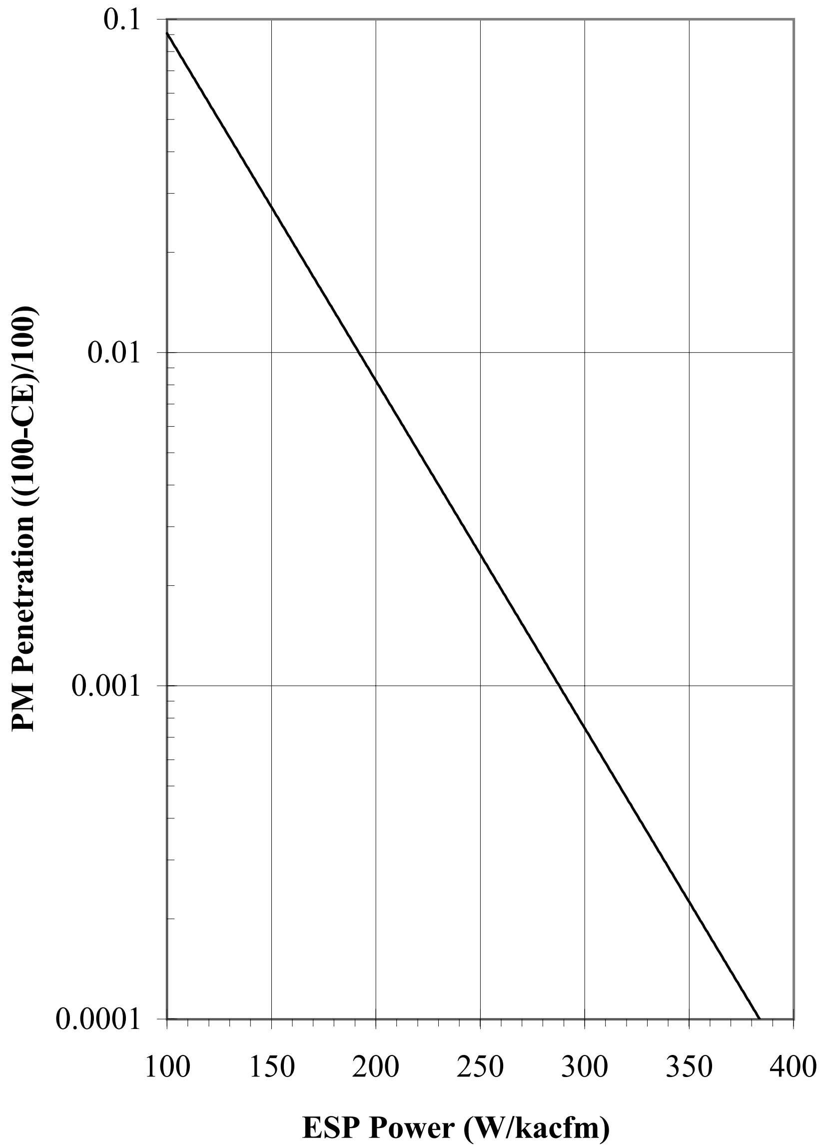


Figure 2-3. Relationship between ESP performance as a function of ESP power input.

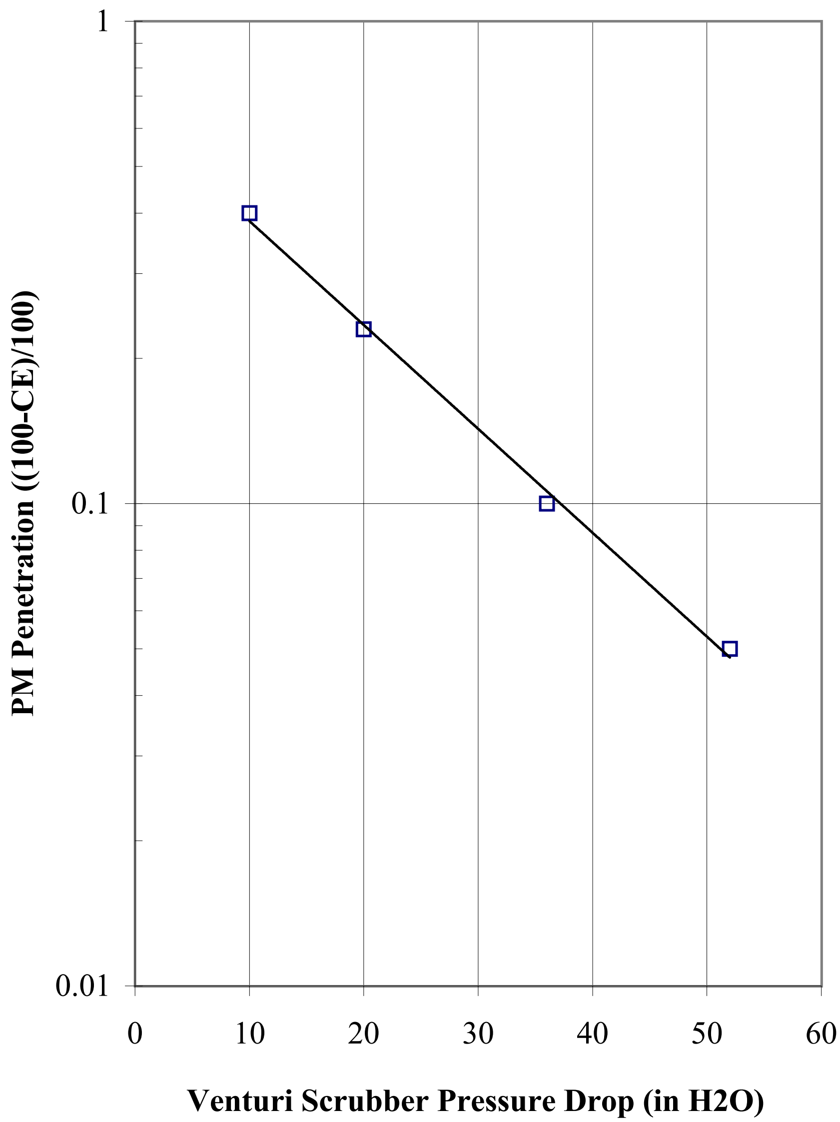


Figure 2-4. Venturi scrubber performance as
a function of scrubber pressure drop.

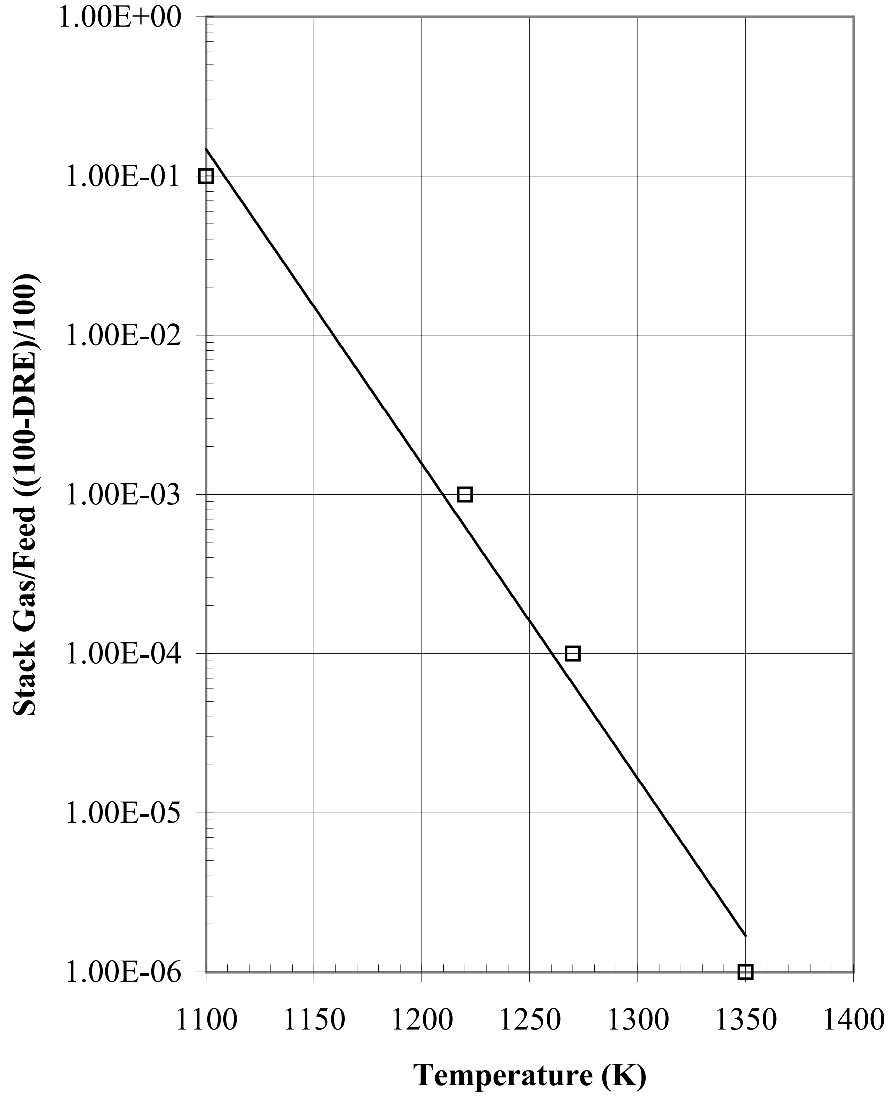


Figure 2-5. Relationship between combustion temperature and DRE for chlorobenzene.

CHAPTER 3

OPERATING PARAMETER LIMITS TO CONTROL PCDD/PCDF

There is currently no CEMS for the direct real-time measurement of PCDD/PCDF in stack gas emissions. It will likely be some years before such a device is available due to technical issues including: (1) the large number of PCDD/PCDF congeners as well as isomers within each congener that require monitoring; (2) PCDD/PCDF are semivolatile compounds at stack temperatures (present potentially in both the gaseous vapor phase, as well as adsorbed on PM); and (3) the need for extremely low detection limits (on the order of parts per billion).

Continuous compliance for PCDD/PCDF is assured indirectly through the monitoring of system operating parameters that influence PCDD/PCDF formation and control. For municipal waste combustors, "Good Combustion Practices" (GCPs) are used as a surrogate for assuring continued compliance with PCDD/PCDF emissions (Kilgroe et al., 1990). Many of these GCPs can be directly used for hazardous waste burners. Potential PCDD/PCDF controls may include:

- Limiting PCDD/PCDF formation by:

  -- Maintenance of adequate combustion quality and efficiency to achieve complete burn out of organics and limitation of organic precursors available for PCDD/PCDF formation.

  -- Avoiding formation from low temperature catalytic mechanisms that can occur in a temperature range of about 400 to 700°F, and can take place during combustion gas cooling and in "dry-type" particulate matter air pollution control devices. This formation involves surface catalyzed reactions where entrained particulate matter provides the reaction surfaces.

  -- Control of feed constituents that are potential PCDD/PCDF formation precursors, such as PCBs, chlorobenzenes, or chlorophenols.

- Use of PCDD/PCDF formation inhibitors. Some limited demonstrations to date have indicated that these may include constituents such as sulfur or ammonia, or other proprietary formulations.

- The control of the feedrate of chlorine has been suggested to be potentially related to PCDD/PCDF control.

• Capturing and/or destroying PCDD/PCDF that have been formed:

  - Capturing with activated carbon. Activated carbon adsorbs PCDD/PCDF vapors. Carbon can be injected into the flue gas stream and removed in a downstream PM control device. Fixed or fluidized carbon beds can also be used.

  - Capturing condensed phase PCDD/PCDF with a PM control device (including vapors adsorbed on activated carbon).

  - Destruction with catalytic oxidizers.

  - Destroying PCDD/PCDF that is contained in the combustor feedstreams. For PCDD/PCDF listed wastes (including those listed as F020, F021, F022, F023, F026, and F027, which are RCRA hazardous wastes under Part 261 because they contain high concentrations of PCDD/PCDF), there is a requirement for achieving “6 nines” destruction and removal efficiency (i.e., 99.9999% DRE).

Specific operating parameters that are required for PCDD/PCDF control are summarized in Table 3-1.

Note that minimization of the formation of PCDD/PCDF or PCDD/PCDF destruction in hazardous waste combustion systems is the preferred control approach compared with PCDD/PCDF capture. PCDD/PCDF capture may only act to transfer it from one emission stream medium to another, and thus the total release of PCDD/PCDF may not be reduced (e.g., removed from flue gas and transferred to solid waste stream).

3.1 COMBUSTION EFFICIENCY

For PCDD/PCDF control, maintaining combustion efficiency and quality involves complete burn-out of organics and limitation of the formation of PCDD/PCDF precursors such as chlorinated or non-chlorinated aromatic compounds (e.g., phenol, benzene), as well as aliphatics

(Addink and Olie, 1995). A variety of parameters may be considered as indicators for maintaining combustion efficiency, including: (1) flue gas CO and HC content; (2) flue gas flowrate; (3) waste feedrate; (4) temperature in combustion chamber(s); (5) waste batch size and feeding frequency; (6) combustion chamber oxygen level; (7) hazardous waste firing system parameters (e.g., liquid burner settings and solid waste feed procedures); (8) feed composition variations; (9) combustion air mixing and distribution; and (10) flue gas PIC content.

The following briefly discusses the rationale for the selection of appropriate limits. Specific monitoring requirements, averaging periods, limit setting bases, etc. are discussed in the DRE compliance Chapter 10 of this document.

(1) CO and HC -- MACT standards for flue gas CO and HC levels are used to ensure combustion efficiency is being maintained. CO and HC flue gas levels are direct indicators of combustion efficiency. Additionally, some studies have suggested that CO may be used as an indirect surrogate for controlling PCDD/PCDF emissions (e.g., Kilgroe et al., 1990).

(2) Flue gas flowrate (or production rate) -- A maximum limit on flue gas flowrate is required as a direct measure of the combustion gas velocity through the combustion chamber(s). It is limited to ensure:

- Flue gas residence times are sufficient to result in adequate flue gas "time at temperature" to assure compliance with the DRE standard and to minimize organic HAP emissions.

- Back pressure at system joints and seals (e.g., at the junction between a rotary kiln and afterburner) is not so high that it results in combustion system leaks.

- Gas flowrate through the air pollution control equipment is not so high it results in the system being overloaded, which may cause the emissions standards to be exceeded.

(3) Waste feedrate -- A maximum limit is required to avoid overcharging the waste combustion chamber. Overcharging may lead to incomplete combustion of feed organics and release of unburned material containing PCDD/PCDF or PCDD/PCDF precursors. For incinerators, waste stream feedrate limits are established for each combustion chamber (and each waste feed location) to minimize combustion perturbations. For industrial kilns, individual waste stream feedrate limits are set for each location where waste is fed (e.g., the hot end,

mid-kiln, or the cold end where raw material is fed). Also, limits are set on both pumpable and non-pumpable wastes.

(4) Combustion chamber temperature -- A limit on minimum temperature in combustion chamber(s)is required. Sufficient temperature is needed to destroy organic waste constituents. Generally, the higher the temperature, the greater the level of destruction of organics because the reaction rate for the destruction of organics compounds and the oxidation of their products of incomplete combustion increases with temperature. For incinerators, limits are required for each incinerator chamber (for example, separate limits for combustors with primary and secondary (afterburner) chambers). For cement and lightweight aggregate kilns, limits are required at each of the waste feed locations. Note that for kilns which feed waste at mid-kiln locations, measurement of kiln back-end temperature may be requested as a surrogate to direct monitoring of mid-kiln temperature.

Also note that the limits are required for each combustion chamber regardless of whether waste is fed into the chamber. Combustion temperature measurement location(s) are identified in the comprehensive performance test plan, and are subject to EPA approval on a site-specific basis.

(5) Batch feeding units -- As discussed in the CO/HC and DRE compliance Chapters 9 and 10, batch feeding limits are not required in general. However, certain batch feeding units may be required on a site-specific basis, as a preventative measure for assuring proper combustion, to establish and comply with a variety of limits on batch feed operating parameters (e.g., batch size, composition, waste volatility, and/or heating content, feeding frequency, oxygen level, etc.). These are used to ensure efficient combustion is being maintained (e.g., minimize oxygen deficiencies, combustor “puffing”, and flame quenching). The determination for the requirement of limits on these operating parameters will be based on a variety of site-specific considerations, including past facility operational performance, number of automatic waste feed cutoffs, facility design and operation, etc.

Comprehensive performance testing must be conducted under simulated “worst-case” batch feeding operating conditions, regardless if the source establishes batch feed operating parameter limits. This should consider the types and quantities of wastes that may be burned, and the range of batch feeding related operating parameters that are expected during subsequent on-going post-test operations.

(6) Combustion chamber oxygen level -- Also as discussed in the CO/HC and DRE compliance Chapters 9 and 10, a limit on oxygen is not required for all facilities in general. However,

for batch feeding systems, a limit on combustor oxygen level may be required on a site-specific basis, as a preventative measure for assuring proper combustion. An oxygen limit may help prevent combustion perturbations.

Both insufficient and excess oxygen levels may lead to increased PCDD/PCDF emissions. Insufficient oxygen results in the formation of PICs which may be PCDD/PCDF precursors; however, insufficient oxygen levels are indicated by high CO and HC flue gas levels, which are required to be continuously monitored. Alternatively, high excess oxygen levels may act to cool the combustion zone, allowing for organics to escape undestroyed. The HC limit should serve as a safeguard against this failure mode. It may not be desirable to operate at high excess oxygen levels since an increase in available oxygen has been shown to increase PCDD/PCDF emissions (e.g., Nottrodt et al., 1990; Manscher et al., 1990; Lenoir et al., 1991).

Other reasons for not generally requiring an oxygen limit include:

-- Difficulty in picking one excess oxygen level that is satisfactory for the combustion of different waste types.

-- Concern about continuously and reliably measuring oxygen concentration at the combustion chamber exit. Measurements are normally made at the stack, where air leakage in between the combustion chamber and the measurement probe location can mask deficiencies in the combustion chamber thus limiting the value of the measurements.

-- Several types of combustion chambers are designed to operate at sub-stoichiometric conditions (pyrolytic or gasification systems), where additional oxygen is provided in downstream combustion equipment. For these systems, a minimum oxygen level for the sub-stoichiometric chambers would be inappropriate.

Although a minimum oxygen level operating limit is not generally required, stack gas oxygen continuous measurement is required to correct other continuous stack gas measurements (e.g., CO, HC, PM) to a common 7% O_2 standard basis.

(7) Operation of hazardous waste firing system -- Limits on parameters to ensure that the hazardous waste firing system is operating properly are to be identified in the comprehensive performance test plan, and are subject to EPA approval on a site-specific basis. These parameters may include for example, for liquid waste burners, waste burner

operating parameters which can ensure adequate liquid waste atomization and efficient waste/fuel/air mixing -- and may include such parameters as atomization fluid pressure, waste heating value, liquid waste viscosity, liquid waste solids content, and burner turndown ratio.

(8) Waste and fuel feed composition variations -- Changes in combustor feed composition may adversely affect combustor operational efficiency. For example, a limit on the minimum waste heating value may be appropriate. Spikes and drops in feed compositions may result in regions of cold and/or oxygen deficient gases. However, no limit on waste heating value (or any other feed composition constituent that may affect combustion efficiency) is required because other limits discussed above suffice for ensuring adequate combustion control.

(9) Air mixing and distribution -- Inadequate mixing between combustion air and waste may lead to oxygen deficient regions and conditions of insufficient residence time at temperature for complete organics burnout. Parameters discussed above adequately ensure combustion quality. Also, certain limits on hazardous waste firing system operating parameters may help ensure proper mixing. Additionally, note that monitoring techniques for parameters that are indicative of air/fuel/waste mixing are not available or demonstrated for full-scale combustors.

(10) PIC monitoring -- Continuous monitoring and control of certain products of incomplete combustion may provide further assurance of good combustion practices and control of PCDD/PCDF emissions. However, due to the lack of comprehensive PIC data to set MACT PIC limits, and the current lack of demonstration of PIC CEMS, limits on CO or HC are used as direct indicators of combustion efficiency.

3.2 LOW TEMPERATURE CATALYTIC FORMATION

PCDD/PCDF can be formed through a low-temperature catalytic formation process, typically occurring as the combustion gas is cooled and/or passed through a “dry” PM control device. Formation due to this mechanism has been shown to be attributable to factors including: (1) combustion gas quenching rate (gas temperature and residence time profile); (2) PM control device temperature; and (3) composition of the entrained PM, in particular its catalytic metals content.

Gas temperature at the inlet of dry PM APCD -- A limit on maximum gas temperature at the inlet of “dry” PM APCDs is required. “Dry” PM ACPDs include ESPs and FFs, which typically operate at temperatures from 300 to 500°F, and at a minimum, levels comfortably above the flue gas dew point (which typically ranges from 120 to 200°F). This limit is not generally applicable to certain dry PM devices such as cyclones and other inertial type collectors where the PM is not suspended in the gas stream for great lengths of time, making the formation of PCDD/PCDF not as likely in these devices compared with FFs and ESPs. Determination of the requirement for maximum temperature limits on these other types of dry PM control devices is made on a site-specific basis depending on gas residence time in the control device, nature of the particulate hold up in the device, operating temperature, etc.

Additionally, for lightweight aggregate kilns (and other units which may have extensive ducting where the flue gas is in a temperature range of 400 to 800°F), it is required to monitor and control the gas temperature near the kiln exit after gas cooling (as opposed to the inlet to the dry APCD). This is to ensure the prevention of PCDD/PCDF formation in the flue gas transfer ducting between the kiln exit and the PM APCD. If a source, for some reason, has difficulty in monitoring temperature at the kiln exit, it can petition the Agency under Section 63.1209 for an alternative monitoring location.

Rationale -- The flue gas temperature profile, in particular that through the PCDD/PCDF temperature formation region, is critical to PCDD/PCDF control (e.g., Fangmark et al., 1994; Gullett et al., 1994; Vogg and Stieglitz, 1986; Kilgroe et al., 1990). PCDD/PCDF has been shown to form when entrained PM and combustion gases are in a temperature range of from 400 to 750°F (with maximum formation occurring around 570°F). Figures 3-1 through 3-3 show examples of the relationship between PCDD/PCDF emissions and dry PM APCD operating temperature. Figure 3-1 shows PCDD/PCDF from all hazardous waste burning cement kilns; Figures 3-2a and 3-2b show data from a well controlled experimental investigation at a single hazardous waste burning cement kiln; and Figures 3-3a, 3-3b, and 3-3c show data from municipal solid waste and medical waste incinerators. The relationship is clearly exponential, where PCDD/PCDF emissions generally tend to increase by a factor of 10 for approximately every 120 to 150°F increase in APCD operating temperature.

Additionally, the residence time in the temperature window is important. The use of rapid quenching generally minimizes formation, whereas slower cooling may result in substantial PCDD/PCDF formation. Particle gas residence times of less than 5 seconds have been shown to be adequate for PCDD/PCDF formation, as discussed below.

Thus, to control PCDD/PCDF formation, it is desired to maintain the combustion gas temperature quenching rate and profile similar to or "faster" than that used in the comprehensive performance testing (specifically the residence time at temperatures in the downstream gas transfer ducting and air pollution control equipment). A maximum limit on the gas temperature at the inlet of a "dry" air pollution control device is generally used to ensure avoidance of operating at temperatures in the ducting and air pollution control system (downstream of the combustion chamber) above that demonstrated in the comprehensive performance tests (where the higher temperatures would potentially be conducive to PCDD/PCDF formation). The use of a limit on the inlet temperature of dry APCDs assumes that the combustion gas temperature and flue gas cooling system operates in everyday operation in a similar manner to that used in the comprehensive performance test, i.e., during other operations, the flue gas profile is comparable to that of the performance testing. Also, note that for certain LWAKs as mentioned both above and below, the limit is applied to the temperature at the kiln exit (as opposed to the FF) because some LWAKs have long flue gas transfer ducts between the kiln exit and the FF, where the flue gas is slowly cooled through the PCDD/PCDF formation temperature range.

Temperature limits to control PCDD/PCDF are not required for wet scrubber air pollution control devices. Wet scrubbers must by design operate at stack gas dew point temperatures, which typically range from 150 to 200°F. Thus, a temperature limit on the wet scrubbing device(s) is not necessary because the gas is not "held-up" in the PCDD/PCDF formation temperature range in the wet scrubber. Note that PCDD/PCDF formation in wet scrubbers is not generally a concern:

- Many facilities use rapid quenching of combustion gases to wet scrubber temperatures of less than 200°F (i.e., gas is cooled quickly through the temperature range of about 400 to 750°F).

- In other cases where wet scrubbing systems are used downstream of "dry" PM control devices, the flue gas exiting the dry PM control device is typically rapidly quenched to the wet scrubbing operating temperature.

Additionally, as discussed above, for units which use "slow" gas cooling, such as those using boilers or heat exchangers, and/or cooling through long flue gas transfer ducts (such as certain lightweight aggregate kilns), additional limits on maximum intermediate location temperatures upstream of the dry PM APCD may be required on a site-specific basis, such as the temperature prior to and/or immediately after cooling locations.

Limit compliance period -- The maximum temperature limit is complied with on a 1-hour rolling average basis. Rationale for the averaging period is discussed in Chapter 2.

Note as well that the strong, non-linear relationship between "dry" PM air pollution control device temperature and PCDD/PCDF emissions is based on emissions testing data from EPA

Manual Sampling Method 23. Method 23 is an integrated measurement over a 2 to 4 hour duration. However, this relationship remains valid over shorter time durations (e.g., 1 hour). Specifically, as mentioned briefly above, the low temperature catalytic PCDD/PCDF formation reactions, which are the basis for the limit on PM APCD operating temperature, have been shown to be rapid (i.e., on the order of seconds, as opposed to minutes or hours):

- In recent testing at a hazardous waste burning LWAK, PCDD/PCDF formation was observed in an uninsulated transfer duct between the kiln exit and the fabric filter, with a gas residence time in the transfer duct of about 6 seconds (EER, 1997). In the first series of testing, the gas temperature was 600°F at the kiln exit and 390°F at the fabric filter. PCDD/PCDF levels of about 2 ng TEQ/dscm were measured. In the second series of testing, the kiln exit gases were quenched rapidly to about 450°F, with a similar fabric filter temperature as in the first series. PCDD/PCDF levels were reduced to 0.5 ng TEQ/dscm.

- Various pilot scale combustor research studies have shown PCDD/PCDF formation rates with gas phase residence times of as little as 2 to 5 seconds in the post-combustion low temperature catalytic formation range (of about 400 to 700°F) are sufficient to explain full scale stack gas PCDD/PCDF levels (e.g., Gullet and Raghunathan, 1997; Gullet et al., 1994; Fangmark et al., 1993; Fangmark et al., 1994; Ismo et al., 1997; Addink and Olie, 1995; Altwicker, 1996; Konduri and Altwicker, 1994).

Thus, the use of a 1-hour rolling average period for compliance with the dry PM APCD temperature limit is appropriate and necessary to better ensure compliance with the PCDD/PCDF standard. In some site specific cases, it may further be determined that shorter averaging periods are appropriate.

Limit basis -- The limit is set based on that demonstrated during the comprehensive performance tests. The 1-hour rolling average limit is set based on the average of the individual run averages (for each pertinent run of the comprehensive performance test).

Measurement techniques -- Flue gas temperature is measured with similar techniques discussed in Chapter 10 for combustion gas temperature (e.g., thermocouples).

<u>Feed restriction on catalytic constituents (e.g., metals)</u> -- Copper, as well as iron and nickel, have been suggested to be responsible for the catalytic reactions that lead to PCDD/PCDF formation (e.g., Naikwadi and Karasek, 1989; Gullett et al., 1990; Hinton and Lane, 1991). However, an operating limit on maximum feedrate of these constituents is not required because: (1) the presence of these metals is difficult to control due to their common nature and occurrence; (2)

recent EPA monitored tests on a cement kiln with an ESP have shown that there is no apparent correlation between PCDD/PCDF and copper feedrates (EER, 1995); and (3) there may be other unknown constituents that are also important to PCDD/PCDF formation, so as a practical matter only limiting these three metals may not result in the control of PCDD/PCDF emissions.

3.3 WASTE CHARACTERISTICS

Waste precursor content -- Certain PCDD/PCDF formation precursors (such as chlorophenols, chlorobenzenes, or chlorinated biphenyls, and other compounds which closely resemble the PCDD/PCDF structure) are suspected to be responsible for high PCDD/PCDF stack gas emissions in some cases. For example, as discussed in the *Technical Support Document for HWC MACT Standards, Volume III: Selection of Proposed MACT Standards and Technologies*, one hazardous waste incinerator that burns polychlorinated bi-phenyls has elevated PCDD/PCDF emissions levels. Thus it may be appropriate to set a limit on the feedrate of suspected PCDD/PCDF precursors. However, other factors such as dry PM control device temperature are typically more important to PCDD/PCDF formation. Additionally, the measurement of all suspected PCDD/PCDF precursor compounds may not be feasible. Thus a requirement for the measurement of PCDD/PCDF precursors in combustor feedstreams on a semi-continuous basis is not required.

Note that hazardous waste analysis for various organics is required (as part of the reviewed and approved waste (feedstream) analysis plan) for determining compliance with site-specific waste acceptance criteria. For example, analysis of waste organics to ensure that Principal Organic Hazardous Constituents used in the performance testing are representative. These criteria are used for determining and assuring the proper acceptance and appropriateness of wastes for thermal treatment, and are set based on site-specific considerations.

Also, the comprehensive performance and confirmatory compliance testing should be conducted using feedstreams that are fully representative with respect to their content of likely PCDD/PCDF precursors based on knowledge of the wastes streams composition that are to be burned (i.e., have similar or higher levels of PCDD/PCDF precursors in the compliance tests than expected in subsequent on-going operations).

Chlorine feedrate -- Limited bench-scale studies have shown a direct relationship between waste chlorine content (and resulting HCl and Cl_2 flue gas emission levels) and PCDD/PCDF stack gas emissions levels (e.g., Gullett et al., 1994; De Fre and Rymen, 1989). However, many evaluations on full scale combustion equipment suggest that there is no clear relationship (e.g., Johnke and Stelzner, 1992; Lenoir et al., 1991; Visalli, 1987). Most recently, a comprehensive study conducted for the American Society of Mechanical Engineers statistically analyzed all available PCDD/PCDF emissions and chlorine feed composition data from tests on municipal, medical, and hazardous waste combustors (Rigo et al., 1995). No statistically significant correlation was discovered between the chlorine feed level and PCDD/PCDF emissions. There were a limited number of tests indicating increased PCDD/PCDF emissions with increasing chlorine loading in the waste feed. However, at least an equal number of tests indicated that increased chlorine loading led to a decrease in PCDD/PCDF stack gas emissions. Also, recent EPA sponsored testing at a hazardous waste burning cement kiln clearly indicated that chlorine feedrate level has no impact on PCDD/PCDF in cement kilns (EER, 1995).

Suggestions as to why there is no apparent strong relationship between chlorine feed and PCDD/PCDF levels include:

(1) The requirement of extremely low levels of chlorine for PCDD/PCDF formation (demonstrated by the detection of PCDD/PCDF emissions from the combustion of relatively chlorine free diesel and distillate oils);

(2) The more dominant influence of other parameters such as PM air pollution control device operating temperature or combustion quality on PCDD/PCDF emissions levels; and

(3) PCDD/PCDF formation has been shown to be sensitive to the chlorine content of the fly ash, and alternatively not very sensitive to the HCl content of the flue gas. Chlorine saturation in the fly ash occurs at low levels of chlorine feed. At higher chlorine feed levels, the HCl gas content increases proportionally, with no effect on the fly ash chlorine content. Thus PCDD/PCDF formation is not significantly impacted by higher chlorine levels.

Note that PCDD/PCDF can be formed when burning very low chlorine-containing wastes. Dow reports detecting PCDD/PCDF at a level of 20 ng/dscm (total PCDD/PCDF, not TEQ) when burning chlorine-free distillate oil. PCDD/PCDF has been found in diesel gasoline engine exhaust, at a level of 5.4 ng TEQ/kilometer. Chlorine contained in the combustion air has been attributed to PCDD/PCDF formation. Inland ambient air can contain 1 to 10 ppb chlorine. The chlorine content of air near the ocean can approach 1 ppm. Thus, ambient air may have from 100 to 100,000 times more chlorine than is theoretically needed to form PCDD/PCDF at a PCDD/PCDF level of 20 ng/dscm (total PCDD/PCDF, not TEQ).

In conclusion, a limit on the maximum chlorine feedrate is not required for compliance with PCDD/PCDF limits. However, note that a maximum feed rate limit for chlorine is required based on limiting of metals volatility and chlorine emissions, as discussed below in more detail, if both total chlorine and LVM and SVM continuous emissions monitors are not used (or chlorine and metals low feedrate waivers are not used, as discussed in Chapter 13).

Also, waste with normal "average" (or greater) levels of chlorine must be used during the confirmatory performance tests.

3.4 FORMATION INHIBITORS

Certain compounds have been demonstrated to inhibit PCDD/PCDF formation. These include sulfur (Gullet et al., 1994; Gullett et al., 1992; Lindbauer et al., 1992; Frankenhaeuser et al., 1993), nitrogenated compounds such as ammonia (Takacs and Moilanen, 1991), and other proprietary mixtures (Horler and Clements, 1994). The inhibitors may function as both a catalyst poison for the low temperature catalytic formation reaction, and also to eliminate PCDD/PCDF precursors that form prior to the catalytic temperature range. Inhibitor parameters affecting performance include inhibitor feedrate and inhibitor specifications.

Note that feedrate limits are not set for inhibitors occurring "naturally" in process raw materials, auxiliary fuels, waste and/or any other feedstreams, such as sulfur in coal used in cement and lightweight aggregate kilns, fuel oil used in incinerators, etc. Limits are set only on inhibitors specifically added for the clearly intended purpose of PCDD/PCDF control.

Inhibitor injection feedrate -- A limit on the minimum inhibitor injection feedrate is required.

Rationale -- Inhibitor performance improves with increased inhibitor feedrate.

Limit compliance period -- The limit is complied with on a 1-hour rolling average period.

Limit basis -- The limit is set based on comprehensive performance test demonstrations. The 1-hour limit is based on the average of the individual run averages (for each different test run).

Measurement technique -- Inhibitor feedrates can be measured with techniques discussed in Chapter 10 for waste feedrate. These may include solid and/or liquid phase measurement techniques.

Inhibitor specifications -- Inhibitor specifications such as chemical (specific chemical constituents in the inhibitor) and physical (used as atomization quality, grain size, etc.) properties can affect performance. Thus, the inhibitor that is used in continuing everyday operations must be shown to have similar or superior performance characteristics compared with that used in the comprehensive performance test.

One compliance option is to limit the brand and type of inhibitor used during everyday operations to exactly what was used in the comprehensive compliance testing.

Alternatively, it may be desired to have flexibility in using different brands and/or types of inhibitors in everyday operation compared with that used in the comprehensive compliance testing. If this is required, the comprehensive performance test plan must document appropriate performance characteristics of the inhibitor that is used in the performance test. These proposed characteristics will be reviewed and approved as part of the comprehensive performance test plan approval by the appropriate Agencies. These characteristics will be used as the basis for inhibitor-type changes. The source must document in the written operating record that the inhibitor that is being used is adequate (i.e., that it meets the specifications of that used in the compliance testing). For inhibitors that are significantly different from that used in the performance testing (such as inhibitors from a new source or vendor), limited retesting and/or information submittals to demonstrate the performance capabilities of the new inhibitor may be needed. Note that these requirements are similar to those discussed below for carbon adsorption systems and caustic injection from dry scrubbers in Chapter 7 (discussing requirements for chlorine control operating parameters).

3.5 AIR POLLUTION CONTROL DEVICES

3.5.1 PM Control Devices

By themselves, PM control devices may have limited PCDD/PCDF control effectiveness for many hazardous waste combustors. At the low concentrations of concern, PCDD/PCDF is generally primarily in vapor form rather than condensed at PM control device temperatures. However, PM control may be effective for units where PCDD/PCDF is adsorbed onto particles containing unburned carbon. It will certainly be of critical importance for facilities which rely on activated carbon (either in beds or injection) for PCDD/PCDF control, such as those with waste heat boilers. Thus all PM control devices discussed in the PM control chapter (Chapter 4) also may be applicable to PCDD/PCDF control. Note that wet scrubbers may not be effective for PCDD/PCDF vapor control because PCDD/PCDF is not generally considered to be soluble in water.

3.5.2 Carbon Injection

Carbon injection may be used for PCDD/PCDF control. Effectiveness is determined by parameters including carbon injection rate, carbon type and specifications, carbon-to-gas mixing, carbon reuse rate, and carbon injection temperature.

Carbon feedrate -- A limit on the minimum carbon injection rate is required.

Rationale -- Increased rates of carbon injection lead to increased levels of PCDD/PCDF control.

Limit compliance period -- The minimum limit is complied with on a 1-hour rolling average period.

Limit basis -- The limit is set based on comprehensive performance test demonstrations. The 1-hour limit is based on the average of the individual run averages (from each pertinent test run of the comprehensive performance testing).

Measurement technique -- Carbon feedrate can be monitored with techniques similar to those discussed for solid waste feedrate monitoring (discussed in Chapter 10). These may include volumetric methods such as screw or belt conveyor feeders; or hopper weight load cell or level indicators.

Carbon type and specifications -- Activated carbon specifications such as the chemical and physical properties can affect performance. Important physical properties can include: specific surface area (as measured with BET (Brunauer-Emmett-Teller) test), pore volume, average pore size, pore size distribution, bulk density, porosity, median particle size, etc. Chemical properties can include: carbon source (bituminous coal, lignite coal, wood), impregnation procedure (typically with sulfur or iodine), carbon composition of sulfur, iodine, chlorine, and/or bromine content, activation procedure (chemical vs steam vs thermal), etc.

Thus, the carbon that is used in continuing everyday operations (beyond the comprehensive performance testing) must be shown to have similar or superior performance characteristics compared with that used in the comprehensive performance test.

One compliance option is to limit the brand and type of carbon that is used during everyday operations to exactly what was used in the comprehensive compliance testing.

Alternatively, it may be desired to have flexibility in using different brands and/or types of carbons in everyday operation compared with that used in comprehensive compliance testing. If this is required, the comprehensive performance test plan must document the important performance characteristics of the carbon that is used in the performance test. These proposed characteristics will be reviewed and approved as part of the comprehensive performance test plan approval by the appropriate Agencies. These characteristics will be used as the basis for carbon-type changes. The source must document in the written operating record that the carbon that is being used in on-going operations is adequate (i.e., that it meets the specifications of that used in the compliance testing). For carbons that are significantly different from that used in the performance testing (such as carbon from a new source or vendor), limited retesting and/or information submittals to demonstrate the performance capabilities of the new carbon is suggested. Note that these requirements are similar to that discussed for inhibitor systems above, and caustic injection from dry scrubbers in Chapter 7 on chlorine control.

<u>Carrier gas flowrate or injection system nozzle pressure drop</u> -- A limit on minimum carbon carrier flowrate is required. Injection nozzle pressure drop may also be used as an indicator of carrier flowrate.

Rationale -- The minimum carrier gas flowrate is needed to ensure that the injected carbon particles are properly fluidized in the pneumatic transfer lines so that they do not agglomerate prior to injection, and to ensure adequate flue gas duct coverage and carbon penetration into the flue gas. Nozzle pressure drop can also be used as a direct indicator of carbon penetration.

Limit compliance period -- The limit is complied with on a 1-hour rolling average period.

Limit basis -- The limit is set based on equipment manufacturer and/or designer specifications. Rationale for the limit is to be included in the performance test plan submitted for Agency review and approval.

Measurement techniques -- Carrier gas flowrate can be measured using techniques such as pitot tube, rotameter, or flow constrictor (similar to those discussed in Chapter 10). Nozzle pressure drop can be measured with pressure taps.

<u>Carbon recycling rate</u> -- In some cases, all or a portion of the injected carbon that is captured in the PM control device may be reused (i.e., reinjected back into the duct for additional PCDD/PCDF capture if the carbon is not saturated). If carbon recycling is used, a maximum limit on the recycling rate may be appropriate on a site-specific basis.

Flue gas temperature -- Carbon PCDD/PCDF capture efficiency tends to increase with decreasing flue gas temperature. Thus a maximum flue gas temperature limit is appropriate. The maximum air pollution control device temperature limit requirement for controlling PCDD/PCDF catalytic formation discussed above is sufficient for assuring that proper temperature in maintained at the carbon injection location.

3.5.3 Carbon Bed

Carbon beds may be used for PCDD/PCDF control. Effectiveness is determined by parameters including flue gas flowrate, bed age, and flue gas temperature.

Flue gas flowrate -- To ensure adequate flue gas residence time in the carbon bed, a limit on maximum flue gas flowrate is required. Limit compliance period, basis, and measurement methods are discussed in Chapter 10.

Carbon type and specifications -- Requirements identical to those discussed above for carbon injection are also applicable to carbon beds.

Bed age -- A limit on maximum carbon age is required. Age is based on the combustion product flue gas flowrate volume that has passed through the bed since change-out.

Rationale -- A limit on bed age is set to ensure that the carbon bed does not become poisoned or saturated with adsorbed flue gas constituents, resulting in a reduction of control effectiveness. Adsorption capacity and capability of the carbon bed must be maintained at an equal or greater level than that used in the comprehensive performance test burn.

Limit basis -- The age limits of the carbon bed segments are set based on the age of the carbon segments used during the comprehensive performance tests -- thus, the comprehensive performance tests must be conducted at the maximum desired age of the carbon bed. For beds with multiple segments that are rotated, maximum age limits for each of the segments are set.

For carbon bed applications on new or reconstructed facilities, and for recent upgrade applications of carbon beds to existing systems, it may not be feasible or possible to establish carbon age limits during the initial comprehensive compliance test. This is because the bed is either brand-new or relatively new prior to the first performance testing. In these cases, carbon bed life may be initially determined based on equipment designer or manufacturer specifications, as documented in the Agency reviewed and approved comprehensive performance test plan. Carbon bed performance should be confirmed through additional performance testing as soon as the desired carbon lifetime has been reached. Note that for desired bed lifetimes of less than around 6 to 12 months, it is likely that the carbon bed age should be set during the initial comprehensive performance testing. This is because the comprehensive performance testing can be scheduled up to 6 months after the compliance date (i.e., the time that the carbon bed equipment is required to be installed and operating) -- and it is likely that the carbon bed will be installed some months prior to the compliance date in actual practice.

Also, petitions for setting carbon bed age using alternative methods is highly encouraged, and may be made to the appropriate Agencies. These may include detailed "breakthrough" calculations based on worst case expected flue gas constituents and known carbon bed adsorption characteristics (e.g., saturation loading levels, etc.), use of accelerated age bench scale simulation testing of carbon bed models, and/or HC/Hg CEMS.

<u>Flue gas temperature</u> -- Flue gas temperature in the bed is important because a temperature spike in the bed may cause adsorbed PCDD/PCDF (and Hg and other heavy metals and organics) to desorb and reenter the stack gas emissions stream. Most facilities utilize some type of PM control device upstream of the carbon bed, and inlet temperature to the PM control device must be maintained below a certain level to avoid PCDD/PCDF formation, ensure control of SVM, prevent damage to the control device, etc.

A separate limit on the maximum carbon bed operating temperature is required. The limit may be complied with at the inlet or the exit of the bed. The limit is complied with on a 1-hour rolling average period, and is based on the average of each of the individual test condition run averages during the comprehensive performance testing.

3.5.4 <u>Catalytic Oxidizer</u>

For catalytic oxidizers, flue gas temperature and flowrate, catalyst age, catalyst type, and flue gas CO, HC, or PIC constituent levels may be indicators of catalyst performance.

<u>Flue gas temperature</u> -- Both a limit on minimum and maximum flue gas temperature is required. Both limits are set at the inlet of the catalytic oxidizer.

Rationale -- Maintaining a minimum inlet temperature is important because catalytic oxidation and destruction rates decrease with decreasing temperature. A maximum limit is important because operation at high temperature can lead to catalyst degradation and reduced catalytic activity.

Limit compliance period -- Minimum and maximum inlet temperature limits are complied with on a 1-hour rolling average period.

Limit basis -- The minimum temperature limit is based on the average of the individual test run averages from the comprehensive performance testing.

The maximum temperature limit is based on equipment manufacturer or designer specifications. Rationale for the limit is to be included in the performance test plan submitted for Agency review and approval.

Measurement techniques -- Flue gas temperature in the catalytic oxidizer control device can be measured with similar techniques to those discussed in Chapter 10 for combustion gas temperature.

<u>Flue gas flowrate</u> -- A limit on the maximum flue gas flowrate through the catalyst is required. This is to ensure that the flue gas has adequate residence time in the catalyst bed. Limit compliance period, basis, and measurement methods are discussed in Chapter 10.

<u>Catalyst age</u> -- A limit on the maximum catalyst age is required.

Rationale -- Catalysts can fail due to deactivation because of poisoning or over-temperature. Deactivation typically will take place over a long time period. However, note that in some less common situations, the deactivation may not be gradual (e.g., deactivation from poisoning or over-temperature may occur in a relatively short time period). In this case, the age limit will not be of use for indicating catalyst failure.

Limit compliance period -- Catalyst age is determined by the amount of combustion flue gas volume that has been processed by the catalyst.

Limit basis -- Due to the difficulty in determining appropriate age limits through comprehensive performance (or confirmatory performance) testing, it is recommended that age limits be set with manufacturer and/or designer specifications that are based on expected operating conditions. Rationale for the limit is to be included in the comprehensive performance test plan submitted for Agency review and approval.

<u>Catalyst type</u> -- The same type of catalyst that is used in the comprehensive performance tests must be used in normal operation. When the catalyst is replaced, it must have equal or better

performance qualities (e.g., design and construction material properties) to that used during the comprehensive testing. Design parameters must include:

- Loading of catalytic metals -- Minimum catalytic metal loading is important because the catalytic metal level is directly related to catalyst operating performance. Loading should be specified in the reviewed and approved performance test plan (e.g., weight catalyst metal per area or weight of catalyst, weight of catalyst per catalyst space velocity, etc.).

- Space velocity -- Minimum space velocity is important because it is a measure of the gas flow residence time in the catalyst; the longer the time, the more potential for reactions to take place.

- Monolith substrate construction -- Catalyst substrate constructions may include monoliths or pellets. The catalyst monolith pore density and catalyst washcoat support should be similar to that used in the comprehensive performance tests.

Rationale for catalyst performance specification operating limits must be included in the comprehensive performance test plan submitted for Agency review and approval.

Flue gas PICs -- Typically, continuous monitoring of flue gas HC, CO, or speciated PICs is used as a direct indicator of catalyst operating performance. However, due to the low levels typical in incinerator flue gases, and the uncertain relationship between these organic compounds and PCDD/PCDF, this may not be indicative of performance for PCDD/PCDF. Limits are thus not required.

Temperature increase -- A flue gas temperature rise across the catalyst unit may provide an indication of catalyst performance because the oxidation processes generate heat. However, for hazardous waste burner flue gas streams which typically have low levels of organics, the temperature increase from organic oxidation/destruction may not be measurable or distinguishable from standard variability and measurement noise. Thus, a limit on the flue gas temperature increase across the catalyst bed is not required.

Pressure drop -- Pressure drop across the catalyst bed may be an indicator of proper catalyst to flue gas contacting. Low pressure drop maybe an indication of holes in the bed, which may allow gas to pass untreated through the bed. However, this parameter is not a required operating parameter because it does not generally have a strong effect on the performance of well-designed, operated, and maintained catalytic oxidizers.

TABLE 3-1. SUMMARY OF DIOXIN/FURAN MONITORING REQUIREMENTS

Control Technique	Compliance Using	Limits From	Averaging Period	How Limit Is Established
Combustion Gas Temperature Quench	Continuous monitoring system (CMS) for maximum temperature at the inlet to the dry particulate matter control device, except lightweight aggregate kilns must monitor gas temperature at the kiln exit	Comprehensive performance test	1-hour	Avg of the test run averages
Good Combustion Practices	CMS for maximum waste feedrates for pumpable and total wastes for each feed system	Comprehensive performance test	1-hour	Avg of the maximum hourly rolling averages for each run
	CMS for minimum gas temperature for each combustion chamber	Comprehensive performance test	1-hour	Avg of the test run averages
	CMS for maximum gas flowrate or kiln production rate	Comprehensive performance test	1-hour	Avg of the maximum hourly rolling averages for each run
	Monitoring of parameters recommended by the source to maintain operation of each hazardous waste firing system[1]	Based on source recommendation	To be determined case-by-case	To be determined case-by-case
Activated Carbon Injection[2]	Good particulate matter control: Monitoring requirements are the same as required for compliance assurance with the particulate matter standard. See Chapter 4.			
	CMS for minimum carbon feedrate	Comprehensive performance test	1-hour	Avg of the test run averages
	CMS for minimum carrier fluid flowrate or nozzle pressure drop	Manufacturer specifications	1-hour	As specified
	Identification of carbon brand and type or adsorption properties	Comprehensive performance test	n/a	Same properties based on manufacturer's specifications

TABLE 3-1. SUMMARY OF DIOXIN/FURAN MONITORING REQUIREMENTS

Control Technique	Compliance Using	Limits From	Averaging Period	How Limit Is Established
Activated Carbon Bed[2]	Good particulate matter control: Monitoring requirements are the same as required for compliance assurance with the particulate matter standard. See Chapter 4.			
	Determination of maximum age of each carbon bed segment	Comprehensive performance test[3]	n/a	Maximum age of each segment during testing[3]
	Identification of carbon brand and type or adsorption properties	Comprehensive performance test	n/a	Same properties based on manufacturer's specifications
	CMS for maximum gas temperature at the inlet or exit of the bed	Comprehensive performance test	1-hour	Avg of the test run averages
Catalytic Oxidizer[2]	CMS for minimum gas temperature at inlet to catalyst	Comprehensive performance test	1-hour	Avg of the test run averages
	Identification of maximum catalyst time in-use	Manufacturer specifications	As specified	
	Identification of catalytic metal loading	Comprehensive performance test	n/a	Same as used during comprehensive test
	Identification of maximum space-time for the catalyst			
	Identification of substrate construct: materials, pore size			
	CMS for maximum flue gas temperature at inlet to catalyst	Manufacturer specifications	1-hour	As specified

TABLE 3-1. SUMMARY OF DIOXIN/FURAN MONITORING REQUIREMENTS

Control Technique	Compliance Using	Limits From	Averaging Period	How Limit Is Established
Dioxin/Furan Formation Inhibitor[2]	CMS for minimum inhibitor feedrate	Comprehensive performance test	1-hour	Avg of the test run averages
	Identification of inhibitor brand and type or inhibitor properties	Comprehensive performance test	n/a	Same properties based on manufacturer's specifications

[1] You must recommend operating parameters, monitoring approaches, and limits in the comprehensive performance test plan to maintain operation of each hazardous waste firing system.

[2] A CMS for gas flowrate or kiln production rate is also required with the same provisions as required for those parameters under the Good Combustion Practices control technique.

[3] Maximum carbon age limits for the compliance period after the initial comprehensive performance test may be based on manufacturer specifications. See 63.1209(K)(7)(i)(c).

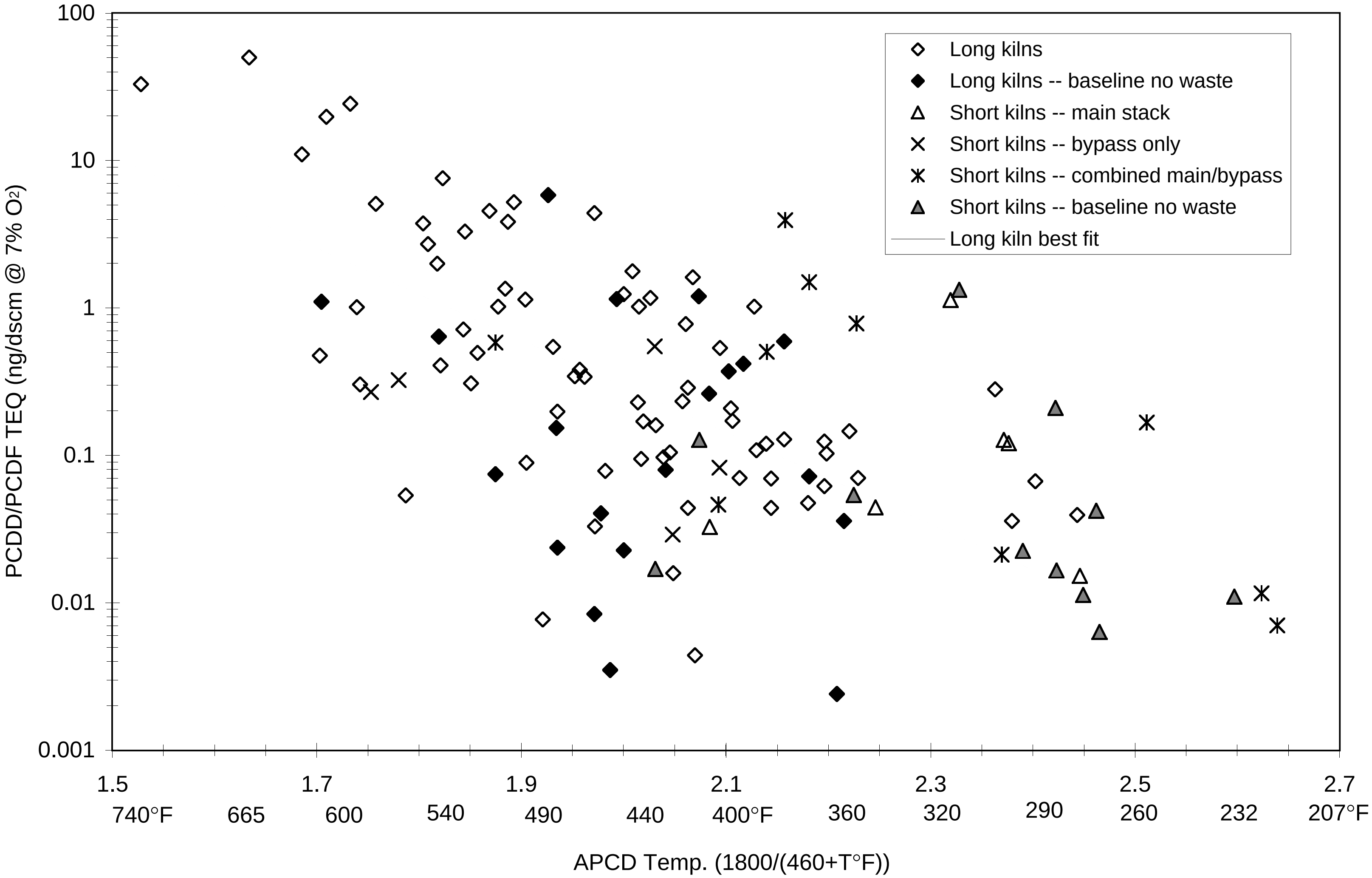


Figure 3-1. PCDD/PCDF TEQ emissions as function of APCD temperature for all cement kilns. (Source: CoC and emissions testing results from cement kilns, contained in the EPA/OSW Hazardous Waste Combustor Database).

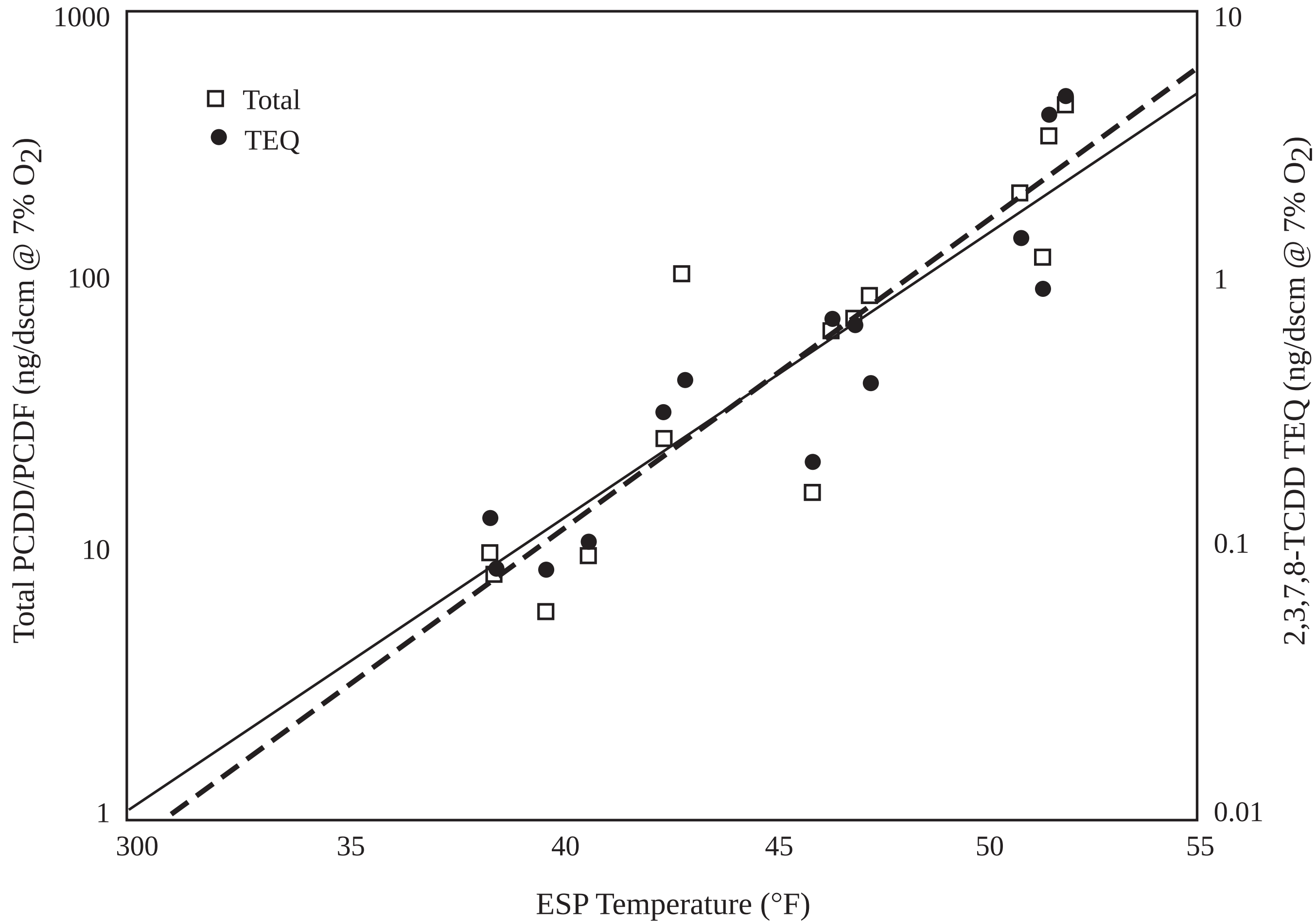


Figure 3-2a. PCDD/PCDF stack gas emissions as a function of air pollution control device (ESP) temperature for a hazardous waste burning cement kiln. (Source: W.S. Lanier, F.M. Stevens, B.R. Springsteen, and W.R. Seeker, "Dioxin Compliance Strategies for the HWC MACT Standards," *Proceedings of the 1996 Incineration Conference*, Savannah, GA, May 6-10, 1996, pp. 587-593).

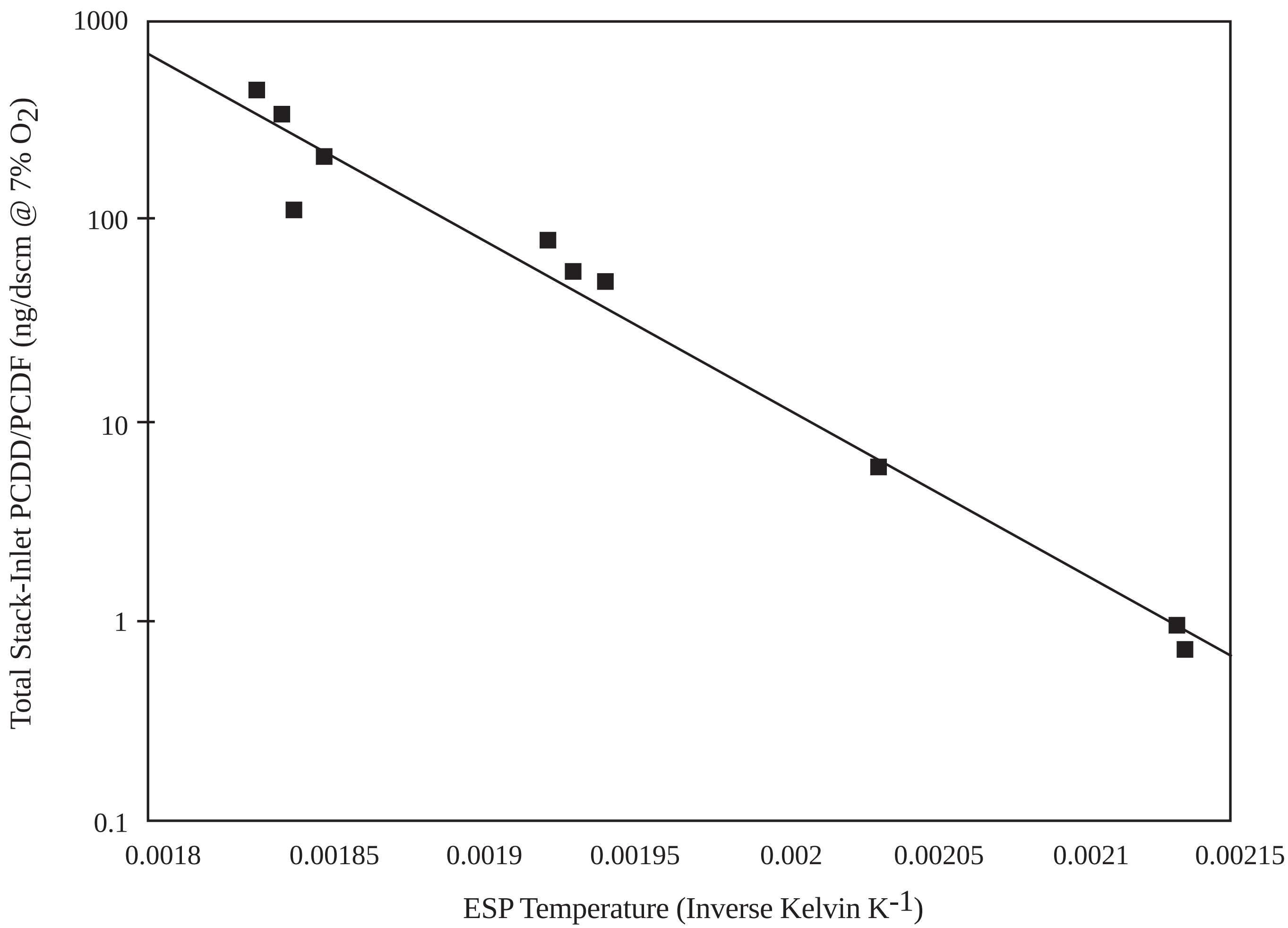
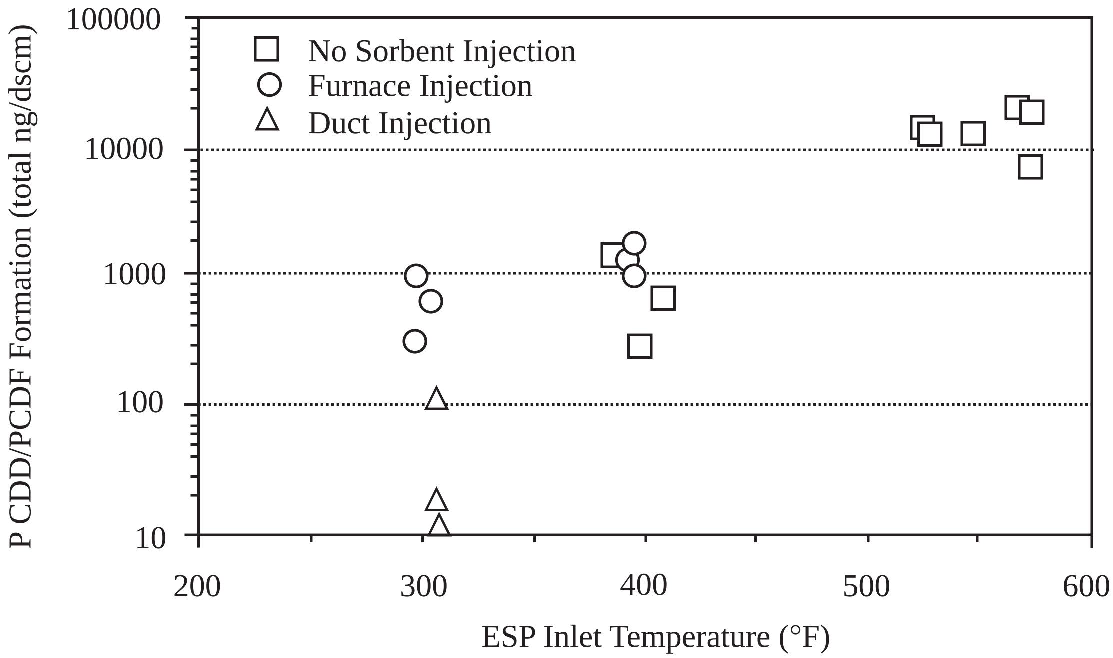


Figure 3-2b. PCDD/PCDF formation across the air pollution control device (ESP) as a function of air pollution control device temperature for a hazardous waste burning cement kiln. (Source: W.S. Lanier, F.M. Stevens, B.R. Springsteen, and W.R. Seeker, “Dioxin Compliance Strategies for the HWC MACT Standards,” *Proceedings of the1996 Incineration Conference*, Savannah, GA, May 6-10, 1996, pp. 587-593).



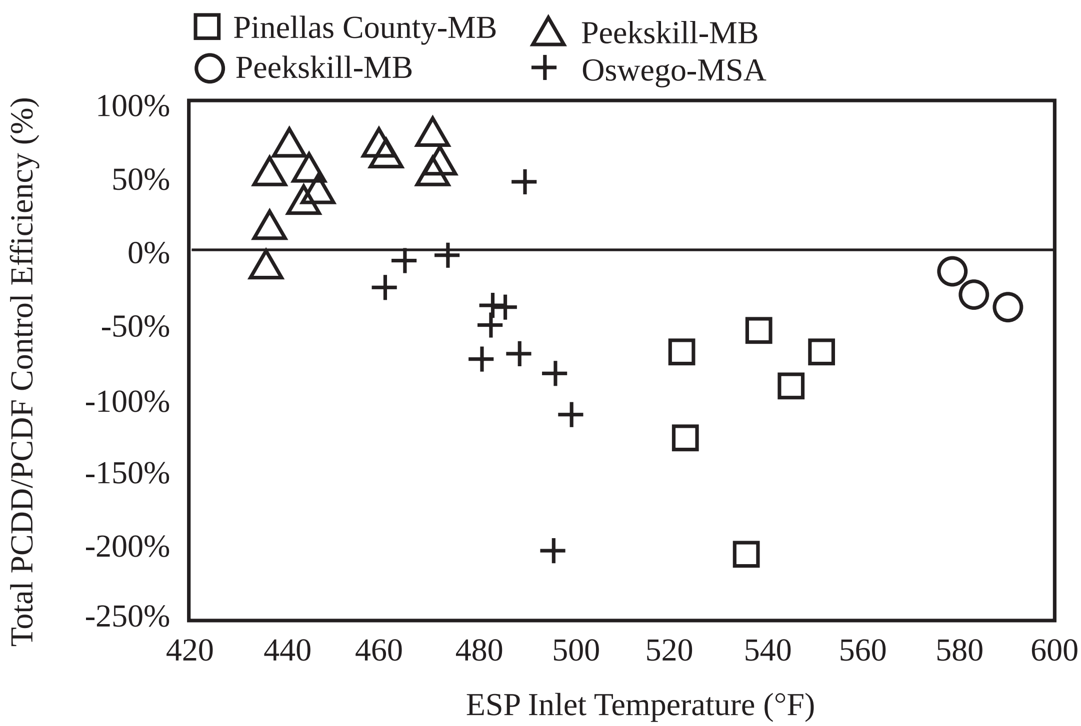


Figure 3-3a. PCDD/PCDF behavior as a function of ESP inlet temperature for Municipal Waste Combustors. (Source: J.D. Kilgroe and T.G. Brna, "Control of PCDD/PCDF Emissions from Municipal Waste Combustion Systems," *Chemosphere*, Vol. 20, No. 10-12, pp. 1875-1882, 1990).

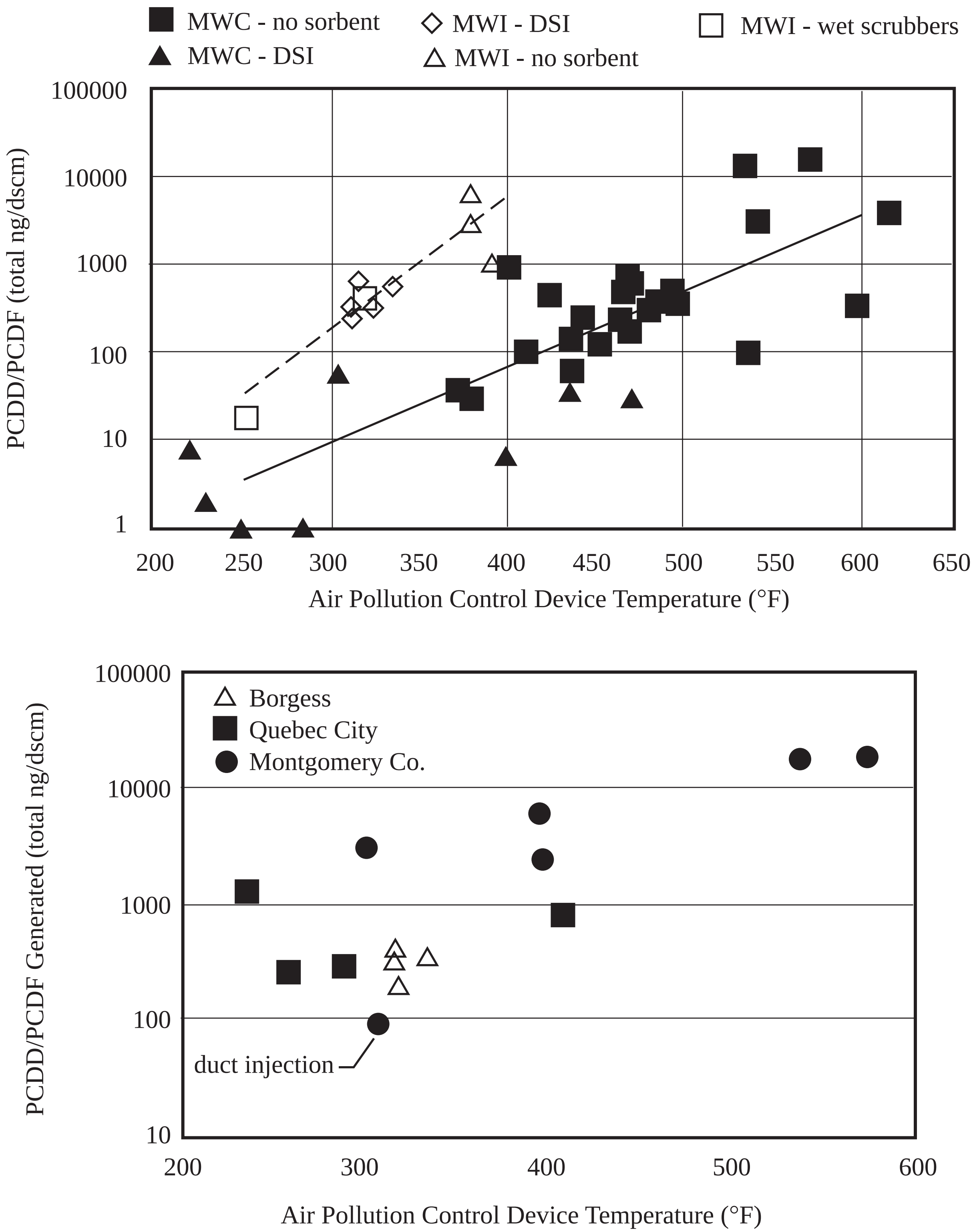


Figure 3-3b. PCDD/PCDF behavior as function of air pollution control device temperature for MWI and MWCs. (Source: W.S. Lanier and T.R. von Alten, "Investigation into the Discrepency between MWI and MWC CDD/CDF Emissions," *Proceedings of the 1992 Incineration Conference*, Albuquerque, NM, May 11-15, 1992, p. 409-417).

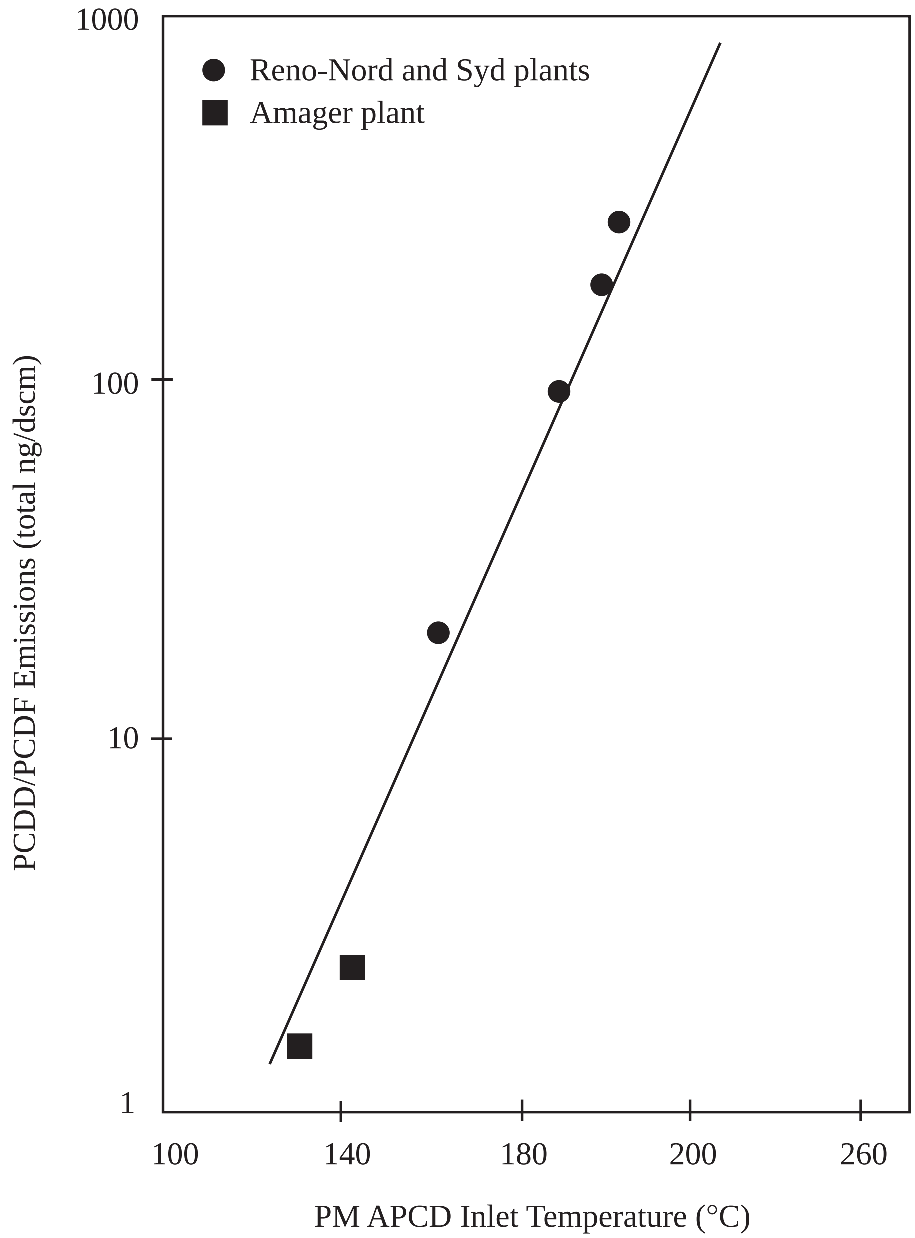


Figure 3-3c. PCDD/PCDF behavior as a function of PM air pollution control device inlet temperature for MWCs. (Source: V. Boscak and G. Kotynek, “Techniques for Dioxin Emission Control,” *2nd Annual International Specialty Conference on Municipal Waste Combustion*, Air and Waste Management Association, pp. 383-398, Tampa, FL, April 15-19, 1991).

CHAPTER 4

OPERATING PARAMETER LIMITS TO CONTROL PARTICULATE MATTER

Particulate matter (PM) is used for control of the non-enumerated CAA metal HAPs -- Co, Mn, Ni, Sb, and Se. The non-enumerated metal HAPs are those metals for which there is not a direct MACT emissions standard. These metals are either low or semivolatile in behavior and are effectively controlled by controlling PM. PM is also used as a compliance parameter for assuring control of the regulated semivolatile and low volatile metals that are absorbed to the PM to levels demonstrated during the comprehensive performance test.

It is preferred, but not required in this rulemaking, that PM be directly monitored on a continuous basis by PM continuous emissions monitoring techniques, as discussed in Chapter 12. As discussed in the final rule preamble, PM CEMS are required to be installed. However, the installation and operation date will be part of future rulemaking. Until this time, the following procedures are used to ensure compliance with the MACT PM standards:

- Cement Kilns -- Opacity monitoring is required for cement kilns to demonstrate compliance with the cement kiln opacity MACT standard. Requirements are discussed in the last section of this chapter. In addition, to ensure compliance with levels achieved during the performance testing, air pollution control device operating parameter limits are also required, as discussed in this chapter. Compliance with Agency reviewed and approved air pollution control device operating and maintenance plans are also required, as discussed in Chapter 14.

- Incinerators and Lightweight Aggregate Kilns -- These units must comply with the PM limit through appropriate system operating parameter limits and Agency reviewed and approved air pollution control device operating and maintenance plans. Alternative uses of opacity monitors and bag leak detector systems may be required, or requested, in certain cases. In particular, bag leak detectors are required for all sources other than cement kilns that use fabric filters.

Operating parameter monitoring and control options for assuring control of PM emissions are discussed in the following subsections, and include limits on: (1) waste feed composition; (2) parameters affecting ash partitioning to the combustion chamber ("bottom ash") and flue gas ("fly ash"); and (3) PM air pollution control device operational parameters that are indicative of control device performance. Operating parameter requirements for assuring control of PM are summarized in Table 4-1. Alternate operating parameters may be requested as part of an Agency-reviewed and approved performance test plan under Section 63.1209(g).

Also discussed at the end of this chapter are:

- Opacity monitors, required for all cement kilns.

- Fabric filter bag leak detection systems, required for FFs when used at all sites other than cement kilns.

4.1 WASTE FEED CONTROL

The ash content of combustor feedstreams, as well as other constituents that may affect PM size distribution, directly impact PM emissions.

Ash feedrate -- For hazardous waste incinerators, a limit on the maximum ash feedrate is required.

Rationale -- A maximum ash feedrate limit is set to prevent "overloading" of the PM air pollution control device which may lead to increased PM stack gas emissions. Because a fraction of the ash fed to the hazardous waste incinerator (contained in the hazardous waste fuels, process raw materials, or auxiliary fuels) is entrained in combustion flue gas, higher ash flue gas loadings generally result in increased levels of PM emissions, especially for systems with no PM air pollution control device, systems with inefficient PM control devices, electrostatic precipitators with inefficient operating and control systems, etc. The entrained ash fraction may be especially high for fluidized bed, rotary kiln, and liquid waste injection type hazardous waste incinerators.

As currently in the RCRA BIF rule, an ash feedrate limit is not required for the industrial process hazardous waste combustor categories of cement and lightweight aggregate kilns. This is because the dominant source of entrained PM from these facilities comes from raw materials and auxiliary fuels (typically coal). In these systems, entrained raw materials comprise the majority of the PM emissions, and thus a variation in the PM loading to the inlet of a PM air pollution control device is primarily a function of factors other than the ash content of hazardous waste fuels (e.g., production rate).

Limit compliance period -- The limit is based on a 12-hour averaging period, which as discussed in Section 2, and Sections 5, 6, and 7 for metals and chlorine feedrate limits, is consistent with the time-period duration of the typical compliance testing condition (3 x 4-hour run test condition).

Limit basis -- The limit is determined as the average of the individual test run averages, from all runs from the pertinent comprehensive performance test condition associated with PM stack gas compliance measurements.

Measurement techniques -- Compliance is based on the determination of ash concentrations in feedstreams and determination of total feedstream feedrates. ASTM Method D482-87 (sample drying and ignition) is recommended for ash analysis of waste feed materials. Feedrate measurement techniques are discussed in Chapter 10.

Characterization requirements during day-to-day compliance operations -- Sampling and analysis for determining feedstream ash content must be conducted "as often as necessary to ensure that the results are accurate and up-to-date and to demonstrate that the unit operates within the permit limits" (U.S. EPA, 1992). Feedstream analysis procedures and frequency are developed on a site-specific basis, and contained in the facility's feedstream analysis plan (similar to the current RCRA required "waste analysis plan"). The feedstream analysis plan must be submitted with Agency-reviewed and approved performance test plan. Recent guidance on developing hazardous waste combustor waste analysis plans is contained in U.S. EPA (1994) and U.S. EPA (1994a). This guidance is directly appropriate for feedstream analysis plans as well.

Note that for each waste stream, at a minimum, the following characterization requirements should be demonstrated:

- Ash (or any other constituent such as metals or chlorine) levels are not present above the specification (limit) level at the 80% upper confidence limit around the mean or the ash characterization measurements. That is to say, the ash feedrate based on 80% upper confidence level ash concentration (based on analysis of a series of representative waste samples) needs to be less than the ash feedrate limit. Sample characterization frequency and size are determined on a site-specific based as part of an Agency-reviewed and approved feedstream analysis plan.

- The analysis could have detected the presence of ash at or below the specification (limit) level at the 80% upper confidence limit around the mean. That is to say, the analytical detection limit must be adequate.

For more information, see "Guidance for Data Quality Assessment -- Practical Methods for Data Analysis," EPA QA/G-9, January 1998, EPA/600/R-96/084.

Waste composition -- Certain feedstream inorganic constituents can affect the size distribution of the generated PM (e.g., salts and metal compounds will tend to form fine particulate which is difficult for the PM air pollution control device to control). Limits on maximum metals and chlorine feedrates are considered elsewhere in this document for other reasons. In site-specific cases, restrictions may be considered on the amounts of other components of waste that are typically burned and suspected to affect PM size distribution, as part of the permit conditions. In general though, there are no specific waste composition limit requirements to control PM size distribution beyond those used for chlorine and metals control.

4.2 ENTRAINMENT

Flue gas flowrate -- A limit on maximum flue gas flowrate through the combustor chamber(s) is used to control the entrainment of PM contained in the flue gas. Decreased gas flowrate acts to maximize the amount of ash that remains in combustor, and minimize the amount of ash that is entrained in the combustor flue gases that must be controlled prior to release to the atmosphere. A maximum limit on flue gas flowrate is also required to address a variety of other needs, including assuring proper air pollution control device operation, combustion efficiency, etc. Compliance period limit (1-hr rolling average), basis (average of performance test highest hourly rolling averages), and measurement techniques are discussed in Chapter 10.

Sootblowing -- Many hazardous waste incinerators use waste heat boilers or heat exchangers for heat recovery. "Sootblowing" is typically used in these systems for cleaning of collected PM from the heat exchanger tubes, because the build-up of PM leads to reduced heat transfer and energy recovery. During the sootblowing, which is typically performed at periodic intervals, increased PM emissions may result compared with operations when sootblowing is not taking place. Current RCRA BIF guidance is to be used for facilities which use sootblowing (U.S. EPA, 1992). This contains procedures for conducting performance testing (for example, at least one of the comprehensive performance test runs must be conducted during a sootblowing episode) as well as averaging equations for determining soot blowing corrected emissions levels. The procedures should be included in the performance test workplan, and should be reviewed and approved on a site-specific basis.

4.3 AIR POLLUTION CONTROL DEVICES

Operating parameters that are indicative of PM air pollution control device performance are discussed below for the following commonly used control devices including: fabric filters, electrostatic precipitators, high energy wet scrubbers, low energy wet scrubbers, ionizing wet scrubbers, other novel wet scrubbers, and high efficiency particulate air filters.

Note that due to the variety of different designs and operations of air pollution control equipment (and new advanced systems that are being developed), as well as differences in site-specific operations, it is not possible to cover (or anticipate) appropriate operating parameters for all types of devices. In these cases, facilities may request additional requirements or a waiver from certain requirements through a petition to the Administrator for alternative monitoring procedures that are appropriate and adequate for assuring proper operation of the air pollution control system under Section 63.1209(g).

4.3.1 Fabric Filters

The collection efficiency of fabric filters is a function of a variety of factors including:

- Filter type and characteristics (e.g., weave, pore size, thickness).

- Face velocity, which is a function of flue gas flowrate and filter material area.

- Cake build-up, which is dependent on the frequency and level of filter cleaning.

- Particulate matter characteristics, especially size distribution.

Filter failure is typically due to filter holes (tearing and/or rupturing), bleed-through migration of particulates through the filter and cake, and small filter cake "pin-holes". Operating parameters that may provide some indication of fabric filter performance include maximum flue gas flowrate and minimum and maximum filter pressure drop. Note that as discussed below, these operating parameters do not provide a good measure of fabric filter performance. There are no set of operating parameters that are indicative of fabric filter performance due to fabric filter failure mechanisms, except for direct PM CEMS (including opacity and bag leak detector systems).

Also note that these operating parameters and this discussion are also generally applicable to other similar type devices which use a filtering media to capture particulate matter. These may include membrane, sintered metal, and ceramic-media filters.

<u>Flue gas flowrate (or production rate alternative)</u> -- A limit on the maximum flue gas flowrate through the fabric filter is required. An increase in flue gas flowrate results in an increase in the air-to-cloth ratio (effective filter face velocity) for a fixed filter fabric area, and a decrease in filter PM control efficiency. Higher flue gas flowrate can also result in increased PM entrainment from the combustion chamber, which results in increased PM loadings to the fabric filter, and potentially increased PM emissions. The compliance limit basis and averaging period are discussed in Chapter 10.

<u>Filter pressure drop</u> -- A limit on both the minimum and maximum pressure drop across the fabric filter device is required.

Rationale -- Pressure drop may provide an indication of:

- Adequate cake build-up. High pressure drop may indicate sufficient cake build-up and efficient filter performance.

- The presence of filter holes. A decrease in pressure drop may indicate the presence of filter holes and resulting low particulate collection efficiency.

- Leakage between sections of the filter housing and the filters.

One limitation of a minimum pressure drop limit is that the pressure change caused by fabric holes may not be measurable, especially in large facilities with multiple chamber filter housing units that operate in parallel arrangements.

A limit on maximum pressure drop is required as well. Operating at a high pressure drop is not desirable because, as mentioned previously, filters fail due to small pinholes which can be created from high pressure drop operation. Additionally, high pressure drop operation is not desirable due to bag blinding or plugging.

Limit compliance period and basis -- Maximum and minimum pressure drop limits are based on manufacturer specifications, and complied with on a 1-hr rolling average period basis. Pressure drop limits are to be requested in an Agency-reviewed and approved comprehensive performance test plan.

Control -- Fabric filter pressure drop is controlled (independent of flue gas flowrate) through: (1) adjusting filter cleaning cycle frequency, intensity, and duration, to control the filter cake buildup, as well as (2) system maintenance practices (e.g., change out of old filters, minimization of leakage between selections of the filter and filter housing, etc.).

Measurement technique -- Pressure drop can be measured with manometer or differential pressure transducers.

<u>Powder leak detection</u> -- Filter holes may be detected with the periodic use of fluorescent powders. Powder is injected onto the filter. Leaks are detected by inspection for the powder on the clean side of the filter using ultraviolet light. The primary limitation of this monitoring technique is that it is a semi-continuous method and thus cannot provide a real-time indication of fabric filter performance. This check is not required as a permit parameter, but may be very useful as a facility maintenance practice.

<u>Filter-bag cleaning cycle frequency, duration, and intensity</u> -- Transient PM emissions spikes are typically directly related to filter-bag cleaning cycles (e.g., with pulse jet, shaking, sonic horns, or other cleaning methods depending on the fabric filter design). Thus it is important to ensure that comprehensive (and confirmatory) tests include such representative cycles within the duration of each of the tests. Additionally, it is important that cleaning cycle frequency, duration, and intensity used in on-going operations are similar to that used in the performance test demonstrations. In some cases, where it may be appropriate to determine actual average emissions levels from test runs with and without cleaning cycles, the RCRA BIF guidance soot-blowing averaging procedure should be used when bag cleaning is an occasional event (U.S. EPA, 1992).

4.3.2 <u>Electrostatic Precipitators</u>

The PM capture efficiency of electrostatic precipitators (ESPs) is a function of a variety of parameters including:

- Specific collection area (a function of ESP plate area and flue gas flowrate).

- Particulate matter characteristics, such as diameter and the resistivity and viscosity of the flue gas, which are difficult to continuously monitor.

- Electric field collection intensity and particulate matter charge intensity (which are both functions of ESP voltage and current).

Thus, monitoring of flue gas flowrate and power input are used to assure ESP performance.

Note that the parameters discussed apply to both dry and "wet" ESPs. For some wet ESP designs, where a continuous liquid film is flushed over the collection surface or spray nozzles are used to continuously flush the collection surface, it is appropriate to set a limit on the solids content of the liquid wash solution, as is done for high and low energy wet scrubbers below. This is especially important for most applications where the liquid stream is recycled.

Flue gas flowrate (or production rate) -- A limit on maximum flue gas flowrate is required. An increase in flue gas flowrate results in an increase in velocity through the precipitator, a decrease in particle residence time between the charging and collecting plates, and a lower ESP collection efficiency. Also, increased flue gas flowrate can result in higher PM loading to the ESP due to increased entrainment from the combustor. Compliance limit basis and period are discussed in Chapter 10.

Power input -- A limit on minimum ESP power input to each "field" is required. The power limit is based on "secondary" voltage and current measurements, which is the power fed to the ESP (as opposed to the primary power fed directly to the Transformer-Rectifier (T-R) sets).

Rationale -- Power input is one of the main factors controlling ESP performance:

- Increased voltage leads to increased electric field strength. This results in an increase in the saturation (or limiting) charge level that the particulate can obtain, and an increase in charged particulate migration rate to the collection electrode.

- Increased current leads to an increased particle charging rate, and an increased electric field strength near the collection electrode due to "ionic space charge" contribution, and thus increased particle transport rate to the collection electrode.

Field testing measurements have confirmed that ESP collection efficiency is a relatively strong function of power input. Efficiency is a combined function of both voltage and current, and has been shown to be a strong function of power density (White, 1963). Thus, because increased ESP performance is directly related to increased voltage and current density, a limit on minimum ESP power (the product of voltage and current as kVA) to each independent field is used as a continuous performance indicator.

Note that potential limitations to the use of a minimum power input limit for ensuring control of PM to levels achieved during the compliance testing include:

- Changes in PM properties and ESP mechanical conditions. In addition to electrical power input, ESP performance is also a strong function of PM properties (PM size distribution and resistivity) and the ancillary mechanical equipment operation (collection plate and discharge wire rapping intensity and frequency, plate and wire alignment, gas flow distribution uniformity, hopper ash removal, etc.). As PM properties change and/or the mechanical equipment degrades, the character of the site-specific power/PM emission relationship can be weak and variable for high PM collection efficiencies which will be associated with the MACT standards. Thus, emission levels can be relatively insensitive to power levels at high ESP performance levels.

- Power levels used during the compliance testing may cause problems under subsequent operations with excessive sparking and back corona:

  -- Excessive "sparking" (localized electrical breakdown of the gas in the interelectrode space), is primarily due to changes in the flue gas composition (resistivity), plate-to-wire alignment, and plate or wire ash buildup. Sparks are associated with a waste of power and loss of ESP efficiency. Typically a spark rate controller limits the sparking to a rate of less than about 50-150 sparks/minute (the spark rate is limited by momentarily reducing the power input, then increasing power, etc.). Thus a maximum limit on spark rate could be used as a secondary indicator of proper power input, where power input reduction is justified if the spark rate is too high.

  -- "Back corona" is due to an electrical breakdown of gas in the collected particulate layer on the plates. This happens when there is an increase in resistivity of the particulate. Under back corona conditions, lower power levels will actually improve performance and reduce emissions.

- For ESP-controlled HWIs, PM inlet loadings in normal operations will be less than those during the worst case compliance testing. Thus, to achieve PM outlet emissions levels during normal operations comparable to those during the compliance testing, lower ESP power (and lower ESP control efficiency) is required compared with levels using during the compliance testing.

- Power loss can occur in between the T-R set and the discharge wires. Power input, as measured at the T-R set, does not account for any power short-circuited enroute to the internal part of the ESP. The wires/cables carrying the high-voltage power from the T-R sets travel through bus ducts (sheet metal cylinders about 2 ft in diameter) and widely spaced areas in the upper portion of the ESP. High-voltage, typically ceramic, insulators are used to support the wire enroute and at the connection to the discharge wire frame. These insulators can "leak" power if they are cracked or have a film of dust or moisture.

- Drift in the electrical meters for measuring power levels can be important. A requirement for quarterly/annual certification or calibration of the meters is a good practice to ensure accurate power input measurements are being made.

However, given these limitations, a general limit on minimum power input is appropriate.

It may be desired to operate under different operating conditions with different ESP power inputs. In this case, compliance demonstration testing should be conducted under multiple modes of operation, each with different power input requirements. For example, for site-specific situations where inlet particulate loading varies widely depending on the type of waste burned, it may be desirable to set multiple ESP power input limits based on waste type being burned. Alternatively, for most cement kiln and lightweight aggregate kilns, and many incinerators burning fairly consistent waste streams, where the inlet particulate matter loading is fairly consistent, a single limit on ESP power input is likely appropriate. See Section 13.7 for a discussion of operating under different modes.

Additionally, power levels used during the comprehensive compliance testing under worst case high inlet PM loadings are generally fully achievable under normal operations where inlet PM loading is reduced. In fact, due to the "particulate space-charge effect", at lower PM loadings, higher current levels (and higher power) are associated with a given voltage input. Thus, it is easier to maintain power input at lower PM loadings compared with higher PM loadings. Also, the primary limitation to power input is "sparking" (which is dependent primary on gas composition, and to a lesser degree, particle composition) and "back corona" (which is dependent primarily on PM resistivity and PM layer properties). Neither of these conditions is a strong function of PM loading.

If, on a site-specific basis, it is determined to be inappropriate to limit power input, a petition for the use of other comparable operating parameter limits (for example, only secondary current or secondary voltage), may be made under the alternative monitoring provision of Section 63.1209(g).

Also, note that for multiple field ESPs, which are common on most larger HWCs, a power input limit on each separate field is appropriate. This is because the ESP power/performance (p/p) relationship varies significantly on a field-by-field basis. ESPs are typically designed so that a similar PM control level is achieved across each field, for example 70 to 80% removal in each successive field. Most of the PM is caught in first field, with much smaller amounts removed in each subsequent field. Alternatively, for constant removal efficiency, the power input is fairly balanced to each field (the power input will increase slightly through each field). This results in a high p/p index for the first field, and a low p/p index for the last field. The use of a total limit on ESP power is not appropriate because it assumes that the p/p index is constant for each field.

Limit compliance period and basis -- A minimum limit is set based on a 1-hour rolling averaging period. The limit is set based on the average of the individual test run averages of comprehensive performance test demonstration.

Measurement Techniques -- Power input is measured directly through voltage and current meters. If meters are not installed on the transformer secondary, a voltage divider can be added on the precipitator side of the rectifier to allow for secondary measurement.

Collection plate cleaning cycle frequency, duration, and intensity -- Transient PM emission spikes are typically directly related to collection plate rapping (cleaning) cycles. Thus it is important to ensure that comprehensive (and confirmatory) tests include such representative cycles within the duration of each of the tests. Additionally, it is important that cleaning cycle frequency, duration, and intensity that are used in on-going operations are similar to those used in the performance test demonstrations. In some cases, where it may be appropriate to determine actual average emissions levels from test runs with and without cleaning cycles, the RCRA BIF guidance soot-blowing averaging procedure should be used when bag cleaning is an occasional event (U.S. EPA, 1992).

4.3.3 High Energy Wet Scrubbers

High energy scrubbers are designed specifically for PM control. They also can be very efficient at acid gas control. High energy scrubbers include common venturi-type scrubbers, as well as novel scrubber designs including free-jet, collision/condensation, and rotary atomizing designs. High energy scrubbers rely on finely atomized water droplets for impacting and collecting PM. Capture efficiency is generally maintained in high energy wet scrubbers by:

- Providing high relative velocity between solid PM and liquid droplet phases to enhance particle/droplet collisions.

- Minimizing the diameter of the atomized liquid scrubber droplets.

- Minimizing entrainment of agglomerated PM/liquid droplets.

Thus, scrubber pressure drop, scrubber solids content (or blowdown rate and system liquid volume), liquid-to-gas ratio, liquid injection nozzle pressure, and liquid surface tension may provide an indication of scrubber performance.

<u>Pressure drop</u> -- A limit on minimum scrubber pressure drop is required.

Rationale -- High energy (e.g., venturi) scrubber removal efficiency is a strong function of pressure drop (and particulate diameter) (U.S. EPA, 1989). Particle capture in venturi scrubbers is a function of the degree of liquid atomization that is achieved and of the amount of mixing and relative velocities between the flue gas particulate and liquid droplets, which are both dependent on the flue gas velocity across the device (pressure drop across the venturi is a direct measure of flue gas velocity).

Limit compliance period and basis -- The minimum limit is set based on a 1-hour rolling average period. It is set based on the average of the individual test run averages from the comprehensive performance test demonstrations.

Control -- Pressure drop is usually automatically controlled through the adjustment of the throat area (e.g., with a cone or nozzle that moves back and forth in the throat; adjustable butterfly value in the throat region; or use of baffle, dampers, or adjustable inserts in the throat area). The pressure drop is typically measured across the entire scrubber, including the demister.

Note that there are some simple system designs where the throat is fixed. For these cases, there may be some difficulty and conflict in setting simultaneously achievable limits on both maximum flue gas flow rate and minimum scrubber pressure drop. Multiple test conditions may be necessary to allow for operation under different modes spanning the desired range of operation. See Section 13.7 for a discussion of operating under different modes.

Measurement Techniques -- Pressure drop can be measured using manometers or differential pressure transducers.

Liquid blowdown rate (or liquid solids content) -- A limit on either: (1) maximum liquid solids content; or (2) minimum liquid blowdown rate and minimum scrubber liquid volume or tank level is required.

Rationale -- Control of the dissolved and suspended solids content of the scrubber liquid is important because increased solids content of the scrubber liquid increases the amount of particulate solids that can be reentrained in the scrubber exit gas. Additionally, high liquid solids content may act to plug system components leading to a deterioration in system performance.

Compliance can be demonstrated by either: (1) direct monitoring of the scrubber liquid solids content; or by (2) indirectly maintaining a minimum liquid blowdown rate and minimum liquid replacement rate or minimum liquid system volume.

Under Option (1), as discussed below, continuous scrubber solids content monitoring techniques are available. Alternatively, under Option (1), periodic scrubber liquor manual sampling and analysis procedures may be used to ensure proper scrubber liquid composition (especially appropriate in cases where solids content of the scrubber liquid is not expected to fluctuate widely). A sampling and analysis frequency of one hour is recommended. An alternative frequency may be requested as part of the comprehensive performance test plan, submitted for Agency review and approval.

Under Option (2), scrubber liquor blowdown rate and scrubber tank volume or level are maintained to ensure that the solids content is maintained at the level demonstrated in the performance testing. Liquid blowdown is the fraction of the liquid captured and removed from the scrubber that is not recycled for reuse back into the scrubber. Greater blowdown means that less recycled liquid is mixed with fresh liquid, and that the liquid in the scrubber is "cleaner". However, more liquid must be wasted. When complying with the minimum liquid blowdown rate, it is also important to ensure that the overall system scrubber liquid volume is properly maintained. Continued depletion in the total liquid system volume (through blowdown and losses of moisture to the stack gases) would lead to an increase in the solids content of the liquor. System liquid volume is maintained through a minimum requirement on the liquor holding tank volumes (monitoring through level indicators for example), or a minimum requirement on replacement liquor addition rate (fresh water recharge rate).

Note that for facilities complying with Option (2) using a limit on blowdown rate and scrubber liquor system volume, it may be appropriate to set limits on the solids content of certain make up liquid streams that are added to the scrubber. Specifically, maximum limits would be set based on those demonstrated in the compliance testing. This would be appropriate for any make up liquid streams that are suspected to have significant solids content or have solids content which may fluctuate widely during normal operations compared with that during compliance testing.

Some wet scrubbers may chose to operate with intermittent, non-continuous liquid blowdown periods. In this case, compliance with a limit on liquid blowdown rate on a continuous basis is not appropriate. Instead, it is preferred that the facility comply directly with a limit on the scrubber solids content under Option (1). However, if this is not practicably determined, it may be appropriate to set limits on liquid blowdown minimum frequency, minimum duration, and minimum blowdown flowrate, and minimum scrubber liquid system volume. When the interval between successive blowdowns is short in comparison to the compliance test, a limit is set based on the minimum blowdown interval used during the compliance test. In situations where the desired blowdown interval is longer than the test interval, the comprehensive performance test should be conducted at the end of the desired blowdown cycle (i.e., just before a scheduled blowdown). The limit on blowdown frequency will be based on the time interval between the previous blowdown event (before the actual compliance test had started) and the end of the compliance test.

Note that a liquor "conditioning" period may be needed prior to testing to establish an equilibrium scrubber liquor composition.

Compliance period and basis -- Under Option (1), if scrubber liquor solids content is monitored directly on a continuous basis, 12-hour rolling average maximum limits are set based on the average of the individual comprehensive compliance testing run averages.

Alternatively under Option (1), if scrubber liquor solids content is monitored manually on an intermittent basis, a default sampling and measurement frequency of once per hour is specified. A petition for an alternative monitoring frequency can be made in the Agency-reviewed and approved performance test plan. Because of the nature of these measurements, there is no appropriate averaging period. Each of the hourly (or other approved frequency) measurements must meet the limit. The use of a composite of samples taken during intervals within the time period may also be requested. The limit is based on the average of periodic measurements made during the comprehensive performance testing runs, with the frequency specified in the performance test plan, and recommended to be taken at least twice per hour during the testing.

Under Option (2) for systems with continuous blowdown operations, 1-hour rolling average limits on blowdown rate and liquid tank volume/level are set. They are set based on the average of the individual test run averages of the comprehensive performance test demonstrations.

Also, as discussed above, for intermittent blowdown systems which intend to comply with the Option (2), the liquid blowdown rate, blowdown frequency, duration, and rate limits are based on those demonstrated in the compliance testing conditions. A petition to the Administrator pursuant to Section 63.1209(g), as part of the comprehensive performance test plan, is needed for these facilities because the regulations do not cover this scenario.

Measurement techniques -- Under Option (1), a variety of scrubber liquor solids content continuous monitoring techniques are available for direct monitoring. These include conductivity, turbidity, and density methods:

- <u>Conductivity</u> -- Liquid "conductivity" meters are able to make an accurate assessment of both the dissolved and suspended solids liquid content.

- <u>Turbidity</u> -- Liquid "turbidity" meters, which operate similarly to stack gas opacity monitors based on solid particle light scattering, may also be appropriate. However, they may have limited or no response to dissolved solids (which are usually dominated by alkali salts).

- <u>Density</u> -- Liquid density monitors use a vibrating element, where the vibration frequency is a precise function of the density of the liquid surrounding the vibrating element. One potential limitation of density monitors is in cases where the suspended and dissolved solids have similar or comparable density to the liquid (i.e., density monitors are only effective at determining solids content when the solids content has a density that is sufficiently different from that of the liquid).

Calibration of these instrument responses with actual dissolved and suspended solids liquid content is critical to the operation of these monitors.

Under Option (2), liquid blowdown rate and liquid addition rate or tank volume can be monitored with a variety of liquid flowrate devices and level indicator devices discussed in Chapter 10.

<u>Liquid-to-gas ratio</u> -- A limit on the minimum liquid-to-gas ratio is required. The liquid-to-gas ratio is determined as the ratio of the scrubber liquid injection rate to the scrubber flue gas flowrate (actual scrubber gas flowrate).

Rationale -- At low liquid-to-gas ratios, capture efficiency decreases due to an insufficient number of liquid droplet targets. Liquid-to-gas ratio is maintained by adjusting the liquid injection rate or flue gas flowrate. Note that at very high liquid-to-gas ratios, efficiency may also decrease due to a change in the droplet size distribution formed in the scrubber. However, due to the lower probability of this occurring and lesser effect on capture efficiency, a limit on maximum liquid-to-gas ratio is not required.

Limit compliance period and basis -- A minimum limit is complied with on a 1-hour rolling average period. It is set based on the average of the individual test run averages from the comprehensive performance test demonstrations.

Note that for this and other "normalized" parameters which are a function of two independent operating parameters (not measured directly by one measurement technique), it may be adequate to set and comply with individual limits on each parameter, and not the ratio. Specifically, the flue gas flowrate is limited to a maximum level for various other purposes. Thus, a single limit on the minimum liquid flowrate is adequate as long as an alternate maximum limit is met on the flue gas flowrate through the scrubber. The liquid-to-gas ratio will always be higher than the performance test level as long as both a minimum liquid rate and maximum gas flow rate are being maintained because both increased liquid flow rate and decreased gas flow rates will result in higher liquid-to-gas ratio.

Measurement techniques -- Liquid-to-gas ratio is determined by measurement of liquid injection rate and flue gas flowrate. Measurement techniques for both of these parameters are discussed in Chapter 10.

<u>Liquid injection nozzle pressure</u> -- In some scrubbers designed for PM control, nozzles are used and relied upon to atomize the scrubbing liquid. For these systems, a limit on minimum nozzle pressure may required to ensure adequate liquid atomization, as determined by permitting officials of a site-specific basis under the provisions of Section 63.1209(g). It is recommended that compliance be based on a 1-hour rolling average time period, and that the limit be set based on manufacturer or equipment designer specifications.

<u>Liquid surface tension</u> -- Scrubber liquid surface tension affects scrubber performance. Decreasing liquid surface tension leads to improved scrubber emissions performance. With high liquid surface tension, particles tend to "bounce" off the liquid droplets and are not captured. High surface tension also has an adverse effect on droplet formation. However, because surface tension is not a dominant parameter for scrubber performance, and there is no easy way to continuously monitor or control it, it is not required as an operating limit.

4.3.4 Low Energy Wet Scrubbers

Low energy wet scrubbers, such as spray towers, tray towers, or packed bed arrangements, are intended primarily for acid gas control. However, some degree of incidental PM control may take place in low energy wet scrubbers through collection of PM in low energy scrubber internals and scrubber liquor. Additionally, low energy wet scrubbers may be an important source of PM emissions due to entrainment of solid-containing scrubber liquor droplets.

Liquid feed atomization is critical for controlling acid gases and PM from certain low energy wet scrubber designs, such as spray towers. For these systems, a limit on liquid feed pressure is appropriate. Alternatively, many other low energy wet scrubber designs, such as packed beds and tray tower designs, do not generally rely on scrubber liquor atomization for control performance. For these systems, a source can petition the Agency under 63.1209(g) to waive a liquid pressure limit requirement.

The primary consideration in low energy wet scrubber operations related to controlling PM emissions is limiting the solids content of the scrubber liquor. An increase in the solids content of entrained scrubber liquor droplets can translate to an increase in PM emissions. Requirements for controlling and monitoring scrubber liquor solids content are identical to that discussed above for high energy wet scrubbers.

4.3.5 Water Spray Quench for Gas Cooling

Water spray quenches are used for flue gas cooling upstream of wet scrubbers. Depending on the arrangement, the quench can be considered either as a separate unit, or contained within the wet scrubber. Scrubber liquor that is removed and recovered in the wet scrubber is almost always treated and recycled back into the scrubber and water quench. Fresh liquid must be continuously added either directly in the quench or mixed with the recycled scrubber liquor to make up for water vapor lost in the stack gases. When a liquor recycle loop is used, limiting the solids content of the recycled scrubber liquor with procedures discussed above for both high and low energy scrubbers is an appropriate indicator of the solids content of the make up water for the quench.

Water spray quenches can also be used for flue gas cooling upstream of “dry” PM collection devices, such as FF or ESPs, or for gas cooling for stack release purposes. In these cases, there is no water recycle loop because all injected water leaves the stack as vapor. A limit on quench water solids content may be appropriate in cases where the quench water has high solids content or where the quench water solids content may be expected to vary significantly from that used in the compliance testing. Also, a quench water solids content limit may be especially appropriate when no downstream PM control devices are used.

4.3.6 Ionizing Wet Scrubbers

Ionizing wet scrubbers are a combination of wet ESPs and packed bed wet scrubber technologies. Thus they have similar operating parameter requirements to those discussed for ESP and low energy wet scrubbers.

4.3.7 Other Wet Scrubber Types

In addition to high energy, low energy, and ionizing types discussed above, there are many other different types of wet scrubbers that can be used for particulate matter control that are difficult to classify. These scrubbers may have many similar types of operating parameters to those discussed above for high and low energy scrubbers. However, some may have other monitoring requirements such as minimum steam/air flow rate or injection pressure for condensing free jet types. In these cases, a petition must be made under Section 63.1209(g) for appropriate alternative monitoring parameters. These should be contained in the Agency-reviewed and approved comprehensive performance test plan.

4.3.8 High Efficiency Particulate Air Filters

High efficiency particulate air filters (HEPA) are typically used on specialized incinerator systems that burn hazardous and radioactive "mixed" wastes for the highly efficient control of PM. The types of monitoring requirements for HEPA filters which are required include:

- Maximum gas flowrate as demonstrated in the comprehensive performance testing, similar to FFs and ESPs.

- Maximum and minimum allowable pressure drop as based on manufacturer or equipment designer/operator specifications. Typically, HEPA filter pressure drops are designed for 1 in. of H_2O when new. As particles are collected, pressure drop increases. When the pressure drop reaches 3 to 4 in. of H_2O the filter is replaced. HEPA filters are not cleaned as in fabric filter operations. Typical nuclear-grade filters are designed to safely handle up to 10 in. of H_2O. Also, a minimum pressure drop limit should be set and complied with on a continuous basis to ensure that there are no leaks or filter blowouts.

Setting of either a minimum or maximum HEPA filter pressure drop limit based on that demonstrated in comprehensive testing is not desirable:

- It is problematic to set limits on pressure drop (maximum or minimum) as demonstrated in comprehensive testing program since HEPA filter pressure drop changes very slowly due to very light inlet PM loadings from the use of a primary coarse and fine particulate control system (such as a fabric filter or scrubber) upstream of the HEPA filters.

- For HEPA filters pressure drop (low or high) should not have a major effect on capture efficiency:

  -- Demonstration of a minimum pressure drop limit is not necessary since with HEPA filters, the individual filter fibers themselves are relied upon for particle collection. HEPAs have many more and much smaller fibers compared with fabric filters (HEPA filter fibers are less than 1 μm in diameter, compared with fabric filters which have fibers sometimes in the range of 50+ μm). Thus, unlike fabric filters, "sieving" and dust cake build-up are not important or relied on for maintaining HEPA filter capture efficiency. In fact, sieving effects are limited because significant filter cake build-up on HEPAs is not allowed due to maximum pressure drop limitations.

  -- At higher filter pressure drop due to a build-up of collected particles, collection efficiency may increase due to a dust cake "sieving" effect as occurs with fabric filters. Alternatively, flue gas face velocities through the filter will increase as the filter pressure drop increases (since the gas velocity increases as the effective area decreases due to particulate build-up and obstruction); capture efficiency will decrease as velocity increases. In any case, particulate build-up resulting in increased pressure drop is likely to have only a limited improvement on HEPA filter performance. Thus demonstration of a maximum pressure drop limit during comprehensive testing is not desirable.

4.4 OPACITY MONITORING REQUIREMENTS

All hazardous waste burning cement kilns are required to monitor opacity as a supplemental means to show continued compliance with the PM standard (in particular, to meet an opacity MACT standard of 20%). Note that all CKs currently operating under the NSPS (constructed after 1971) have opacity monitors. Information about which pre-1971 CKs are already using opacity monitors is incomplete; although many do use opacity monitors to meet state and local regulations.

It is preferred to use a continuous opacity monitor (COM) (transmissometer). COM installation, operation, and quality assurance and quality control requirements are discussed in the Performance Specification PS - 1 (Appendix B of 40 CFR Part 60). Compliance with the opacity limit is required on a 6-minute block average period. Measurements must be taken at least once every 10 seconds. COMs are required for all main and bypass stacks. No multiple stack averaging is allowed for opacity monitoring.

If it is not feasible for installation or operation, the source can petition to use EPA Method 9 “Visual Determination of the Opacity of Emissions from Stationary Sources”. For example, this may be appropriate in cases where there are multiple stacks or a “monovent”. Method 9 is required to be used on a daily basis. Duration of the individual Method 9 tests must be at least 30 minutes.

4.5 FABRIC FILTER BAG LEAK DETECTION REQUIREMENTS

Combustion systems that use baghouses (fabric filters) are required to use “bag leak detector systems” (BLDS) to identify baghouse malfunctions as part of the baghouse operating and maintenance program described in Chapter 14. Note that BLDS are not required for cement kilns because they are required to demonstrate compliance with an opacity limit with a continuous opacity monitor.

BLDSs are required under the MACT standards for secondary lead smelters, and have been proposed for several other MACT rules, including primary lead smelters, primary copper smelters, ferroalloy production, mineral wool production, and wool fiberglass manufacturing.

The BLDS that is used must: (1) be certified by the manufacturer to be capable of detecting PM emissions at concentrations of 1 mg/acfm; and (2) provide output of relative PM loadings. Several types of instruments are available from a variety of commercial vendors for this purpose. They include the PM CEMs discussed in Chapter 12 based on light scattering (e.g., in-situ light scattering and light scintillation monitors), as well as “triboelectric” or “tribokinetic” monitors which detect PM based on electric charge transfer. Note that the triboelectric monitors are being (or have been) used by secondary lead smelters, some LWAK and CKs, as well as two HWIs. Additionally, light scintillation instruments are used by many secondary lead smelters.

Specific BLDS requirements are to be included in an Agency-reviewed and approved operating and maintenance plan. They may be based on guidance on the installation and use of the BLDS, contained in U.S. EPA (1997) (U.S. EPA, “Fabric Filter Bag Leak Detection Guidance,” EPA Office of Air Quality Planning and Standards, EPA-454/R-98-015, September 1997). This guidance is summarized briefly below.

Initial adjustment of the BLDS is conducted by adjusting the sensitivity and signal averaging period to establish a "baseline" instrument response that is approximately 5 to 10% of the instrument scale range; and to respond to bag cleaning PM spikes to about 30% of the scale. It is suggested that the averaging period be set at about 10 to 15 seconds to dampen peaks from bag cleaning spikes. Next, an "alarm" set point is determined. The alarm set point is the instrument response level that is determined to be an indicator of baghouse malfunction (e.g., broken bag), and may be set conservatively at 2 to 3 times the baseline response. It is recommended that an initial 30-day (or longer) test period be used to determine sufficient BLDS instrument sensitivity and response to avoid frequent false alarms.

Following an alarm indicating a baghouse malfunction, a corrective measures plan must be followed, as contained in the operating and maintenance plan. The corrective measures plan details the corrective actions that will be taken to fix the baghouse.

Recommended BLDS quality assurance and control checks include a monthly "response" test, and monthly instrument electronic drift tests, as also detailed in the operating and maintenance plan.

Note that BLDS alarms do not have to be tied to hazardous waste automatic waste feed cutoff systems. Although, the corrective action plan must be initiated and completed as soon as possible.

TABLE 4-1. SUMMARY OF PARTICULATE MATTER MONITORING REQUIREMENTS

Control Technique	Compliance Using	Limits From	Averaging Period	How Limit Is Established
For Incinerators, Limit on Maximum Ash Feedrate	Sampling and analysis of feedstreams for ash and a continuous monitoring system (CMS) for feedstream flowrate	Comprehensive performance test	12-hour	Avg of the test run averages
Wet Scrubber: High Energy and Ionizing Scrubbers	CMS for maximum flue gas flowrate or kiln production rate	Comprehensive performance test	1-hour	Avg of the maximum hourly rolling averages for each run
	For high energy wet scrubbers only, CMS for minimum pressure drop across scrubber	Comprehensive performance test	1-hour	Avg of the test run averages
	For high energy wet scrubbers only, CMS for limit on minimum scrubber liquid flowrate and maximum flue gas flowrate or CMS for limit on minimum liquid/gas ratio	Comprehensive performance test	1-hour	Avg of the test run averages
All Wet Scrubbers	CMS for limit on minimum blowdown rate plus a CMS for either minimum scrubber tank volume or level, or	Comprehensive performance test	1-hour	Avg of the test run averages
	CMS for solids content of scrubber water, or	Comprehensive performance test	12-hour	Avg of the test run averages
	Manual sampling for solids content of scrubber water[1]	Comprehensive performance test	1-hour	Avg of manual sampling run averages
Fabric Filter[2]	CMS for minimum pressure drop and maximum pressure drop across each cell	Manufacturer's specifications	1-hour	n/a
Electrostatic Precipitator and Ionizing Wet Scrubber[2]	CMS for secondary voltage and current to each field to monitor limits on minimum power input (kVA)	Comprehensive performance test	1-hour	Avg of the test run averages

[1] Unless you elect to comply with a default sampling/analysis frequency for solids content of the scrubber water of once per hour, you must recommend an alternative frequency in the comprehensive performance test plan that you submit for review and approval.

[2] A CMS for gas flowrate or kiln production rate is also required with the same provisions as required for those parameters for wet scrubbers.

CHAPTER 5

OPERATING PARAMETER LIMITS TO CONTROL MERCURY

Operating parameter monitoring and control requirements for assuring control of mercury emissions are discussed, including potential limits on: (1) mercury feedrate; (2) chlorine feedrate; (3) combustion temperature; and (4) mercury air pollution control device operating parameters. Operating parameter requirements for assuring control of mercury are summarized in Table 5-1.

Alternatively and preferably, mercury can be directly monitored on a continuous basis by mercury continuous emissions monitoring techniques (with either total species or elemental mercury monitoring devices), as discussed in Chapter 12.

5.1 COMBUSTOR OPERATING PARAMETERS

<u>Mercury feedrate</u> -- A limit on maximum mercury feedrate (total from all feedstreams) is required.

Rationale -- The amount of mercury fed to the combustor directly affects mercury flue gas emissions and the ability of the air pollution control equipment to remove mercury. Mercury emission rates generally increase with increasing mercury feedrates, as discussed in Chapter 12 of the companion *Technical Support Document for HWC MACT Standards, Volume III: Selection of MACT Standards and Technologies*. A limit is set on maximum total mercury feedrate (contained in all combustor feedstreams including hazardous waste, raw materials, and fossil fuels). Unlike low volatile metals, no limit is set on maximum total mercury feedrate in pumpable hazardous wastes because mercury is generally highly volatile in any form (i.e., pumpable vs non-pumpable).

Limit compliance period and basis -- The mercury feedrate limit is set on a 12-hour rolling average basis. The limit is based on the average of the individual test condition averages (average of each different pertinent test run of the pertinent comprehensive performance test condition where mercury stack gas compliance is being demonstrated).

The total mercury feedrate limit is based on the sum of the mercury feedrates in each different combustor feedstream used during the compliance testing.

Treatment and handling of feedstream non-detects during compliance testing for setting and complying with feedrate limits -- For feedstreams used during compliance testing for which mercury (or semivolatile or low volatile metals, chlorine, or ash) is present at levels below the method quantitation (or "detection") limit, separate mercury feedrate limits are set on those particular feedstreams. The limit for these waste streams is a "feedrate limit as non-detect", based on the full non-detect levels measured in the performance testing (as opposed to the use of one-half of the detection limit or "zero" for non-detect measurements).

There are no requirements for achieving certain detection limits (i.e., limits on minimum detection limits that must be obtained are not specified). This is due primarily to the difficulty in identifying a single (or multiple) detection limit that is appropriate for various feedstreams due to feedstream matrix impacts on achievable detection limits. Instead, site-specific target detection limits are to be submitted in an Agency-reviewed and approved comprehensive performance test plan and accompanying waste analysis plan. Evaluation of appropriate detection limit levels is based on considerations including:

- Costs associated with achieving different mercury detection limits during day-to-day operations; and

- Estimated maximum mercury emissions that would be projected to be associated with the feedstream at the detection limit (considering if appropriate any likely mercury control in the system), and comparison of this level with the emissions standard. For example, the use of higher detection limits may result in less assurance that the source is continuously complying with the emission standard.

Note that for compliance with the performance test waiver provisions of Section 63.1207(m) as discussed in Chapter 13 for units feeding low levels of metal/chlorine, requires a source to assume mercury is present at the full detection limit if the feedstream analysis results indicate mercury is not present at detectable levels. However, CKs and LWAKs may assume mercury is present in the raw material at one-half of the detection limit if the feedstream analysis determines mercury not to be present at detectable levels.

If, at any time during day-to-day operations, the feedstream analysis determines detectable levels in the non-detect feedstream, the facility is not considered to be "out of compliance", provided that:

- The total system feedrate (considering the detectable levels in the feedstreams, above or below the detection limit achieved in the performance test) is less than the total system feedrate limit determined from the compliance testing; or

- The total mercury feedrate converted to an emissions concentration assuming no system control (i.e., 0% system removal efficiency) is less than the mercury MACT standard (as calculated pursuant to the provisions of Section 63.1207(m), the low metals/chlorine feedrate emissions waiver).

Additionally, because detection limits will vary depending on waste matrix, analytical equipment and procedures, etc., it is envisioned that there will be some allowance for achievement of detection limits of the feedstream during day-to-day operations above (within reasonably attainable detection limits) those levels demonstrated in the performance testing. The acceptable upper detection limits will likely be specified in an Agency-reviewed and approved waste (feedstream) analysis plan. This will be addressed further in rule implementation guidance.

Handling of non-detects during day-to-day compliance operations -- Procedures for the treatment of non-detects in individual feedstreams when determining compliance with total feedrate limits will also be addressed in future rule implementation guidance. In particular, how to add feed rates from individual non-detect feedstreams to other detected (and/or non-detected) feedrates from other feedstreams to determine the total mercury feedrate. Likely options include considering non-detect measurements as either full detection (as in current BIF compliance procedures), or at one-half the detection limit.

Note that as discussed above, for the purposes of complying with the performance test waiver provisions of Section 63.1207(m), mercury must be assumed to be present at the full detection limit, except for mercury non-detects in raw material feedstreams, where it may be assumed that mercury is present at one-half of the detection limit.

Measurement techniques -- Mercury feedrate is monitored by determining the mercury concentration in each feedstream and determining the flowrate of each feedstream. Mercury analysis (digestion and analytical techniques) is recommended with SW-846 7470 or 7471 (cold vapor atomic absorption spectroscopy) or any other test method demonstrated to have performance capabilities comparable to or better than SW-846 methods. Feedstream measurements techniques are similar to those discussed in Chapter 10.

Characterization requirements during day-to-day compliance operations -- Waste characterization requirements for assuring that mercury feedrates in all combustor feedstreams during day-to-day operations are below the allowable limit demonstrated in the compliance testing are specified in the facility's feedstream (waste) analysis plan. Requirements are identical to those discussed in Chapter 4 for ash characterization for PM control.

Characterization requirements for natural gas, process air, and vapor recovery system feedstreams -- Characterization of the metals and halogen content of natural gas, process air, and vapor recovery system feedstreams is not required to the same degree or frequency as waste and other feedstreams. For natural gas and process air, as discussed below, this is due to generally low (or non existent) metals and halogen content. For vapor recovery system feedstreams, this is because it is difficult, costly, and often dangerous to sample these feedstreams. Sampling frequency should be requested on a site-specific basis in the facility's waste analysis plan, considering the expected or documented range of metals and/or halogen levels, and difficulty in sampling. At a minimum, one-time assessments must be made of feedstream metals and/or halogen levels. This could, for example, be based on natural gas vendor characterization data. Expected levels of metals and halogens in these feedstreams (and rationale for these levels) must be contained in the Agency reviewed and approved waste analysis plan, as part of the comprehensive performance test plan. These levels must be accounted for when documenting compliance with applicable feedrate limits.

Various natural gas data indicate that metals and halogen levels are typically very low:

- Natural gas metals and chlorine analyses from three hazardous waste and natural gas cofired boiler CoC trial burn reports show that metals and chlorine concentrations are all very low (less than 0.2 ppmw). Specifically, mercury ranges from 0.0005 to 0.01 ppmw (likely based on non-detect measurements).

- Results of a recent survey on the composition of over 20 different natural gas samples, from GRI (1995), showed that mercury was non-detect at a level of 0.02-0.2 $\mu g/m^3$; arsenic was also always non-detect. Chlorinated organics were always non-detect; although no total or organic chlorine levels were reported.

- EPA's "ICCR" database has mercury stack gas emissions from 5 different natural gas fired heaters and boilers. All are non-detect at levels of less than 0.5 μg/dscm.

- Only certain volatile forms of chlorine and mercury are potentially contained in natural gas. Solid phase LVM or SVM would not be expected to be contained in the gas phase.

Chlorine and mercury may be present in the "raw" natural gas taken directly from the gas field. However, the gas is processed and cleaned prior to delivery. This cleaning involves condensing out moisture and other impurities in the raw gas; this cleaning process will act to remove chlorine, mercury, and other volatile constituents. In fact, condensation of mercury onto natural gas cleaning and processing equipment is a known problem because the mercury is corrosive to the equipment.

Chlorine feedrate -- Chlorine feedrate may be important when wet scrubbers are used for mercury control since wet scrubbers can be effective at controlling certain soluble mercury/chlorine compounds, but not effective at controlling many unchlorinated mercury species. Thus a limit on minimum chlorine feedrate may be technically appropriate. However, as a practical matter, because only small amounts of chlorine are required for the typically low levels of mercury in hazardous wastes, a minimum limit on chlorine is not used. Additionally, a minimum limit on chlorine feedrate could be directly counterproductive for controlling chlorine and other metals stack gas emissions levels, where an increase in chlorine feedrate leads to a corresponding direct increase in chlorine and certain metals emissions.

Combustion chamber temperature -- At typical mercury feedrates and combustion temperatures, all mercury vaporizes in the combustion chamber and remains in the vapor phase through the entire system (including the lower temperature of the air pollution control equipment, which for wet scrubber systems may be around 150 to 190°F). Thus, a maximum limit on combustion temperature is not generally required for the control of mercury emissions. A limit on maximum combustion chamber temperature would only be appropriate in very site-specific cases of extremely high mercury feedrate and low combustion chamber temperature, where it may be possible that the equilibrium vapor pressures of the mercury may be exceeded at combustion chamber temperatures.

5.2 AIR POLLUTION CONTROL DEVICES

5.2.1 Wet Scrubbers

Wet scrubbers may be effective at controlling certain soluble forms of mercury, primarily mercury chloride ($HgCl_2$). Additionally, scrubbers can control elemental mercury with the use of certain scrubber additives, such as sodium chlorite or potassium permanganate, that function to oxidize elemental mercury to a scrubber liquid soluble form.

Operating parameters that are indicative of mercury control for wet scrubbers are for the most part similar to those covered and discussed for chlorine control.

Note however, that some recent work has indicated that scrubber liquor pH and/or its oxidizing/reducing capacity can have an important affect on mercury control of wet scrubbers. Use of low pH acidic oxidizing scrubber liquid solutions may enhance the control of elemental mercury. Additionally, with high pH reducing liquids, captured soluble mercury may be reduced back to elemental forms in the scrubber liquid, and re-released from the liquid during liquid recycle. Both of these considerations may suggest that a maximum scrubber liquor pH be set in the compliance test to ensure sufficient Hg control (i.e., the wet scrubber mercury control as demonstrated in the compliance test). A maximum scrubber liquid pH is opposite to the minimum liquid pH limit that is set and used to ensure chlorine control. Thus, in certain cases where wet scrubber mercury control is considered important and where it appears that scrubber liquor pH is important for Hg control, it may be appropriate to require separate compliance tests for determining a scrubber liquor pH operating range, based on both a maximum limit as determined in the mercury compliance test, and a minimum limit based on the chlorine compliance test. Also, if the wet scrubber is staged, or if two wet scrubbers are operated in series, it may be appropriate to establish a maximum pH limit on one scrubber (or stage) for mercury control, and a minimum pH limit on the other for chlorine control.

Additionally, where scrubber liquid additives are used specifically for mercury control, it may be appropriate to set additive usage rate limits (such as mass of additive per gas volume treated).

Also, it may be important to conduct sufficient HWC operations in a time period prior to the compliance test in order to establish a representative scrubber liquid equilibrium composition during the compliance test.

Note that if a “total species” mercury continuous emissions monitor is used, then no monitoring of operating parameters related to mercury is required. However, if only an elemental mercury (Hg°) continuous emissions monitor is utilized, wet scrubber operating parameters may need to be monitored because the non-elemental (e.g., ionic mercury) emissions are not accounted for by an elemental mercury monitor. This issue should be addressed in a petition submitted to the Agency pursuant to Section 63.8(f) (i.e., the petition where a source requests to use a mercury CEMS).

5.2.2 Carbon Injection

Carbon injection can be used for controlling mercury emissions. Operating parameters that are indicative of mercury control are identical to those discussed for PCDD/PCDF control.

5.2.3 Carbon Beds

Carbon beds can be used for controlling mercury emissions. Operating parameters that are indicative of mercury control are identical to those discussed for PCDD/PCDF control.

5.2.4 Others

Other techniques that may be used for mercury control include selenium filters, sodium sulfide injection, and noble metal filters, all of which are discussed in Chapter 3 of the companion document *Technical Support Document for HWC MACT Standards, Volume I: Description of Source Categories*. Sodium sulfide injection monitoring parameters may be analogous to those for carbon injection. Selenium and noble metal filter parameters may be analogous to those for carbon beds and fabric filters.

TABLE 5-1. SUMMARY OF MERCURY MONITORING REQUIREMENTS

Control Technique	Compliance Using	Limits From	Averaging Period	How Limit Is Established
Limit on Maximum Total Mercury Feedrate in all Feedstreams	Sampling and analysis of feedstreams for mercury concentration and a continuous monitoring system for feedstream flowrate[1]	Comprehensive performance test	12-hour	Average of the test run averages
Activated Carbon Injection	Monitoring requirements are the same as required for compliance assurance with the dioxin/furan emission standard. See Chapter 3.			
Activated Carbon Bed	Monitoring requirements are the same as required for compliance assurance with the dioxin/furan emission standard. See Chapter 3.			
Wet Scrubber	Monitoring requirements are the same as required for compliance assurance with the hydrochloric acid/chlorine gas emission standard. See Chapter 7.			

[1] This limit applies to all feedstreams, except natural gas, process air, and feedstreams from vapor recovery systems.

CHAPTER 6

OPERATING PARAMETER LIMITS TO CONTROL SEMIVOLATILE AND LOW VOLATILE METALS

Semivolatile (SVM) metals that are directly regulated via emissions standards are lead and cadmium. Low volatile (LVM) metals that are directly regulated via emissions standards are arsenic, beryllium, and chromium. This chapter discusses operating parameter monitoring and control requirements for assuring control of SVM and LVM emissions. Potential parameters that affect SVM and LVM emissions include:

- Combustor operating parameters:
  - Metals feedrate
  - Metals volatility, which is primarily a function of:
    - Chlorine feedrate
    - Combustor temperature
  - Combustor gas flowrate
- Air pollution control device operational characteristics

Operating parameters that are required for LVM and SVM control are summarized in Table 6-1.

Alternatively and preferably, direct flue gas continuous emissions monitors for SVM and LVM metals may be used in place of the system operating parameter requirements. As discussed in Chapter 12, multi-metal CEM development continues to advance through recent limited demonstrations at various hazardous waste incinerators. However, to date, CEM performance, accuracy, reliability, etc. have not been adequately demonstrated to a degree that enables requirement of these monitors on a national basis. Thus, the operating parameters discussed in this chapter are likely to apply for some time to all HWCs.

6.1 COMBUSTOR OPERATING PARAMETERS

6.1.1 Metals Feedrate

A limit on maximum metals feedrate is required. This includes limits on pumpable vs non-pumpable metal-containing wastes.

Rationale -- The quantity of metal fed to the combustor directly affects emissions. Specifically, metals emission rates increase with increasing metals feedrates, as discussed in Chapter 12 of the companion *Technical Support Document for HWC MACT Standards, Volume III: Selection of MACT Standards and Technologies*.

For LVM, limits are set on:

- Maximum total feedrate (in all streams including hazardous waste, raw materials, and fossil fuels).

- Maximum total metals feedrate in pumpable hazardous wastes.

Different limits are set for LVM in pumpable feedstreams because metals in pumpable streams partition at a higher rate to the combustion flue gas (and thus are emitted at a higher rate) than metals in non-pumpable feed streams.

As discussed for Hg, for SVM limits are only set on maximum total feedrate, because partitioning between the combustion gas and bottom ash or product does not appear to be strongly affected by the physical state of the feedstream. This is because for typical SVM levels and combustion chamber temperatures, all SVM is predicted to vaporize to the combustion gas.

It was considered to set limits for each different location that wastes are fed (i.e., individual limits for each different waste feed location) because factors affecting metals emissions may vary at the different feed locations. However, this is not included in the final rule.

Limit compliance period and basis -- The SVM and LVM feedrate limits are set on a 12-hour rolling average basis. As discussed in Chapter 2, the 12-hour period is based on the typical overall time period duration of the comprehensive compliance testing condition (3 x 4-hour tests). The limits are based on the average of the individual test run averages (i.e., averages of each of the pertinent comprehensive performance test condition runs).

Handling of detection limit measurements -- Consideration of non-detect measurements is similar to that discussed for mercury feedrate limits in Chapter 5. The one difference is that when complying with the performance test waiver provisions pursuant to Section 63.1207(m), CKs and LWAKs must assume SVM and LVM are present at the detection limit in the raw material if the feedstream analysis determines that SVM and LVM are present at non-detect levels.

Measurement techniques -- Feedrates are monitored by determining the SVM and LVM concentrations in each feedstream and by determining the flow rate of each feedstream.

Metals analysis methods (digestion and analytical techniques) are outlined SW-846 (U.S. EPA, 1992). Metals analytical techniques are summarized in Table 6-2. The appropriate sample digestion technique (SW-846 Series 3000 Method) is chosen depending on the feedstream phase and analytical method to be used. Alternate (non-SW-846) analytical techniques may be used if demonstrated to have comparable or superior performance.

Feedstream feedrate (solid and liquid) measurement techniques are discussed in Chapter 10.

Characterization requirements during day-to-day compliance operations -- Waste characterization requirements for assuring that SVM and LVM feedrates in all combustor feedstreams during day-to-day operations are below the allowable limit demonstrated in the compliance testing are specified in the facility's waste analysis plan. Requirements are identical to those discussed in Chapter 4 for ash for PM control.

Characterization requirements for natural gas, process air, and vapor recovery system feedstreams -- Requirements are identical to those discussed for mercury in Chapter 5.

Metals spiking -- The grouping of metals by expected volatility behavior (and resulting partitioning in the combustor system) generally allows for the use of only one metal within each grouping to be used as a surrogate for other metals in the volatility grouping during performance testing (i.e., spiking of combustor feedstreams is only required for one metal in each of the volatility groupings to demonstrate compliance). However, on a site-specific basis, if there is reason to suggest that metals behavior within the volatility group is different (for example, based on previous testing results), individual metal feedrate limits (on individual metals within the same volatility grouping) may be determined to be appropriate. In this situation, individual metal feedrate limits could be avoided by spiking the metal with the worst SRE.

6.1.2 Chlorine Feedrate

An operating limit on maximum chlorine feedrate to the combustion system is required. The limit is based on the total chlorine content in all feedstreams; this includes organic and inorganic chlorine sources.

Rationale -- Chlorine levels may affect metals emissions because chlorinated metal species are more volatile than unchlorinated metals and are thus more difficult to control (Barton et al., 1990).

*Limit compliance period and basi*s -- The chlorine feedrate limit is complied with on a 12-hour rolling average period basis, similar to that for the LVM and SVM feedrate limits. The limit is also based on the average of the individual test run averages. Chlorine feedstream analysis requirements are similar to those discussed above for Hg feedrate control.

Handling of detection limit measurements -- Consideration of non-detect measurements is identical to that discussed for mercury feedrate limits in Chapter 5.

Measurement techniques -- Chlorine feedrate is monitored by determining the concentration of chlorine in each feedstream, and by determining the flowrate of each feedstream. SW-846 Method 5050 (or ASTM D808) for sample preparation and SW-846 Methods 9250, 9251, 9252, or 9253 for analytical are recommended for chlorine sample analysis. An option for aqueous wastes is to analyze for total organic halogens with SW-846 Methods 9020 or 9022 and inorganic chloride according to the methods discussed above. Other non SW-846 methods may be requested as long as method performance is shown to be comparable or superior to SW-846 methods.

6.1.3 Combustor Gas Flowrate

A limit on maximum combustor gas flowrate is used to ensure that metals entrainment from the combustion chamber in fly ash is minimized, in an identical manner to that used for PM control in Chapter 4. Limit compliance period, basis, and measurement techniques are identical to that discussed in Chapters 4 and 10.

6.1.4 Combustion Chamber Temperature

For the BIF rule, an operating limit is set on maximum combustion chamber temperature (U.S. EPA, 1992). This is to ensure operation at temperatures that do not lead to enhanced volatilization of metals feeds. Increasing combustion chamber temperature leads to increased metals volatility, which may result in an increase in metals stack gas emissions. Highly volatile metals remain as vapor and may pass uncaptured directly through most air pollution control systems. SVM (and to a small extent some LVM) generally vaporize fully in the combustion chamber and condense fully at lower air pollution control system temperatures either into or onto particles in the sub-micron size range, which is the most difficult to remove in an air pollution control system.

However, further evaluation suggests that although a maximum limit on combustion chamber temperature may make sense for the control of metals emissions based on theoretical considerations and limited laboratory or pilot scale research, in practice it is not considered as necessary because:

- Most metals are typically either highly volatile or highly non-volatile at common combustion temperatures (supported by both theoretical and experimental test evidence). Thus small changes in temperature (as would typically be expected in combustion units) do not impact metals volatility (and resulting stack gas emissions levels).

- Evaluation of trial burn data does not provide any support for a relationship between combustion chamber temperature and stack gas metals emissions levels.

For SVM, in most cases, typical combustion chamber temperatures are high enough so that all of the metals volatilize in the combustion chamber. Thus, increases in temperature beyond typical combustion chamber operating levels will not impact the SVM load to the air pollution control system (and resulting stack gas emissions levels). This is supported by analyses of the trial burn data showing that SVM partitions mostly to the captured particulate matter and dust in the air pollution control system. In general, all SVM vaporizes in the combustion chamber and condenses at the lower operating temperatures of the air pollution control system (EER, 1994). This behavior is also supported by theoretical modeling (Clark and Rizeq, 1991).

LVM would not be expected to vaporize entirely in the combustion chamber. Thus, operating at higher than demonstrated combustion chamber temperature may result in additional metals vaporization and an increase in load (and emissions) to the air pollution control system (as mentioned above, vaporized metals condense on small particles which are difficult to capture in the air pollution control system). However, this is not generally important because the amount of vaporization at typical combustion temperatures, and the amount of additional vaporization at higher than typical temperatures, is usually negligible compared to the amount of LVM contained in non-volatilized entrained flue gas particulate matter, which is present at particularly high levels in cement kilns, aggregate kilns, fluidized and rotary kiln incinerators, and pulverized coal boilers.

Analyses of trial burn data does not indicate a strong relationship between combustion chamber temperature and LVM (or SVM or mercury) stack gas emissions. Note that this may be due to the difficulty in observing trends from data taken from a number of facilities; there is a considerable amount of variance from one facility to another due to differences in control devices, feed rates, operating parameters, and measurement techniques. These effects of facility specific differences may obscure trends due to a single parameter. In particular, combustion chamber temperature is difficult to accurately measure, especially from cement and lightweight aggregate kilns. Temperature measurements are taken at different locations with different instruments, making it difficult to compare results from different facilities. In any case, the fact that there is not a strong relationship between combustion chamber temperature and metals stack gas emissions (LVM as well as SVM or mercury) implies that other parameters besides combustion chamber temperature are more dominant in influencing stack gas emissions levels.

Additionally, the requirement of a maximum temperature limit is in conflict with demonstration of operation at a minimum temperature limit for adequate organics destruction. Thus the addition of a maximum combustion chamber temperature limit would increase the testing condition requirements (and thus costs and complexity) of the comprehensive compliance testing program.

Also note that prolonged operation at maximum temperature during the comprehensive performance test (and normal operations) is not desirable because it can be destructive to the kiln refractory.

Note that under strictly theoretical considerations, it has been shown that for particular cases, higher combustion chamber temperatures should lead to increased metals emissions (for instance, certain SVM at very high feedrates where complete vapor saturation is predicted to occur) (Clark and Rizeq, 1991). But as discussed above, actual emissions data have not shown a strong trend which supports this theory.

6.2 AIR POLLUTION CONTROL DEVICES

PM air pollution control device type and associated control parameters discussed in the PM compliance Chapter 4 are also equally applicable to SVM and LVM control. Additionally, the operating temperature of the air pollution control device or system may be particularly important to SVM control. Specialized sorbent specifically designed for metals control may also be used.

<u>Operating temperature of air pollution control device</u> -- For metals which volatilize in the combustion chamber and are carried out with the flue gas, the temperature of the particulate matter control device influences the subsequent degree of condensation and control (lower temperature results in a higher degree of condensation and control). Thus, a maximum temperature limit is required for dry APCDs to help to ensure that these types of metals emissions are being adequately controlled. The maximum limit is based on a 1-hour rolling average period. It is determined on the average of the individual test run averages from the comprehensive performance testing. Note that for wet scrubbers, which operate at lower dew point saturation temperatures, a minimum temperature limit is not required.

Note that a maximum control device temperature limit is also used to control PCDD/PCDF formation. The applicable resulting limit is the minimum of the maximum limits as determined by the PCDD/PCDF and metals testing in cases where compliance with these standards are conducted under separate performance test conditions.

<u>Metal capturing sorbents</u> -- Sorbents such as kaolin, bauxite, silica, alumina, and clays, are currently being developed to control semivolatile metals emissions (e.g., Wu et al., 1995). No hazardous waste burning facilities are currently intentionally using these control techniques, however they may in the future. The sorbents can be added directly to the feed, or injected separately downstream of the combustor. Operating parameter requirements may be analogous to carbon injection and dry scrubbing technologies discussed in other chapters. Note that in site-specific cases where waste and other feedstream materials may potentially contain these types of metal capturing ingredients, monitoring of waste composition during the comprehensive performance testing (and during subsequent regular operation) may be appropriate in cases where it might be expected that composition of wastes and/or feed materials are likely to significantly change.

6.3 EXTRAPOLATION

The "upward" extrapolation of SVM and LVM feedrates and associated emissions rates from levels demonstrated during the comprehensive performance test to higher allowable feedrate and emissions rates can be requested on a site-specific basis. Linear upward extrapolation from the "origin" (at a metal feed and emissions rate of zero) can be conservatively used to allow for higher metals feedrate limits while continuing to ensure that the facility is within the MACT emissions limits. This is because metals system removal efficiencies tend to stay the same or increase as the feedrate increases. This has been shown based on theory and statistical analysis of experimental test results, as discussed in *Technical Support Document Vol. III: Evaluation of Metals Emissions Database to Investigate Extrapolation and Interpolation Issues*, prepared to support the MACT HWC NODA, 62 FR 24211, May 2, 1997. This applies to all metals types and volatility groupings.

The conservative nature of the "upward" extrapolation procedure is shown in Figure 6-1. The emissions level predicted at a higher feedrate based on linear extrapolation through the origin and from measured emissions levels at a lower feedrate is greater than or equal to the actual emissions levels at the higher feedrate (based on the expected relationship between metals feed and emissions rates). Alternatively, because "downward" extrapolation may not always be conservative, as also shown in Figure 6-1, it is generally not allowed.

A request for the use of extrapolation for setting allowable metals feedrate limits must be contained in the comprehensive performance test plan, which is submitted to EPA at least 1 year prior to the actual testing. The extrapolation methodology will be reviewed and approved by the Administrator. The extrapolation submittal must discuss:

- Rationale for the selection of the comprehensive performance test metals feedrates, and desired extrapolated feedrates. In particular, the feedrate levels must at a minimum represent those in typical "normal" waste streams. It should also reflect the potential variability and fluctuation in normal waste metals levels, which will depend on the heterogeneity and other characteristics of the waste. The discussion should include a listing of the various waste streams that are treated, and results of historical metals characterization efforts. This is to ensure that the amount of extrapolation that is needed is minimized.

- Rationale for the selection of the physical form and species of the metals used, also based on expected waste characteristics.

- A maximum extrapolated feedrate that would be desired, again considering the historical metal feedrate data. Specifically, EPA does not want sources to extrapolate to allowable feedrates that are significantly higher than their historical range of feedrates. The requested extrapolated feedrates should be limited to the upper end of historical metals feedrate ranges that a source has actually fed, unless the source documents that future operations will necessitate higher metals feedrate limits.

- Discussion of characterization procedures to be used to ensure that metals feedrates and emissions rates documented in the comprehensive performance test plan are highly accurate. Some spiking will likely be required to increase confidence in the measured feedrate levels used to project higher allowable feedrate limits. Errors associated with sampling and analyzing heterogeneous waste streams can be minimized by spiking known quantities.

Also, after the performance testing, EPA will review the testing and extrapolation results to confirm that they have been interpreted properly and that the extrapolation procedure is appropriate for the source.

The extrapolation procedure that is to be used will depend on the extent and quality of the metals feedrate and emissions data. To ensure that the extrapolation is "conservative" in nature (i.e., produces projected emissions levels at the projected feedrate that are upper bounds on that expected), it is recommended that the extrapolation be based on either the lowest SRE within a test condition, or some statistically based analysis procedure. This might include:

- For cases where a large amount of data has been compiled from different feedrate levels (for example, through many tests over the years), extrapolation from a statistically based analysis of the specific facility data may be appropriate, such as from a worst case test condition average considering typical statistical variability of the within-test condition runs, or a linear regression of the condition average (or individual run) feedrate and emissions rate data, considering some upper confidence limit bound.

- For cases where more limited and/or widely spread data are available, extrapolation from the worst case lowest observed SRE that is not an outlier.

- Extrapolation from a single test burn condition based on determination of the "Upper Confidence Limit" of the test condition average (as suggested by CKRC in their May 1997 NODA comments). Specifically, this involves using a single test condition average, and a within test condition standard deviation based on either site specific data or the demonstrated variation observed in other similar type tests.

- For small extrapolations to feedrates relatively close to demonstration testing levels, more aggressive extrapolations may be warranted, such as those from a test condition median or average. Alternately, for larger extrapolations, a more conservative procedure is generally appropriate.

Note that the extrapolation procedure presented in the May 1997 NODA based on the use of the "Universal Variability Factor" may be appropriate for conservatively ensuring that all future individual test condition runs are less than the extrapolated feedrate, as required by the current RCRA BIF rules. However, compliance with the HWC MACT rule is based on a 3-run test condition average, thus, this procedure will produce highly conservative feedrate limits.

Extrapolation procedures will be further addressed in rule implementation guidance.

TABLE 6-1 SUMMARY OF SEMIVOLATILE AND LOW VOLATILE METALS MONITORING REQUIREMENTS

Control Technique	Compliance Using	Limit From	Averaging Period	How Limit Is Established
Good Particulate Matter Control	Monitoring requirements are the same as required for compliance assurance with the particulate matter standard. See Chapter 4.			
Limit on Maximum Inlet Temperature to Dry Particulate Matter Control Device	Continuous monitoring system (CMS)	Comprehensive performance test	1-hour	Avg of the test run averages
Limit on Gas Flowrate to Control Metals Entrainment	CMS for maximum gas flowrate or kiln production rate	Comprehensive performance test	1-hour	Avg of the maximum hourly rolling averages for each run
Limit on Maximum Total Semivolatile and Low Volatile Metal Feedrates from all Feedstreams	Sampling and analysis of feedstreams[1] for metals concentrations and a CMS for feedstream flowrate	Comprehensive performance test	12-hour	Avg of the test run averages
Limit on Maximum Total Pumpable Low Volatile Metal Feedrate from all Feedstreams	Sampling and analysis of feedstreams[1] for metals concentrations and a CMS for feedstream flowrate	Comprehensive performance test	12-hour	Avg of the test run averages
Limit on Maximum Total Chlorine Feedrate from all Feedstreams	Sampling and analysis of feedstreams[1] for chlorine and chloride concentrations and a CMS for feedstream flowrate	Comprehensive performance test	12-hour	Avg of the test run averages

1 This limit applies to all feedstreams, except natural gas, process air, and feedstreams from vapor recovery systems.

TABLE 6-2. EPA SW-846 ANALYTICAL METHODS FOR METALS IN FEEDSTREAMS

Metal	SW-846 Analytical Method
Low Volatile Metals	
Antimony	6020, 7040, 7041
Arsenic	6020, 7060, 7061
Barium	6010, 6020, 7080
Beryllium	6010, 6020, 7090, 7091
Chromium (total)	6010, 6020, 7190, 7191
Cobolt	6010, 6020, 7200, 7201
Manganese	6010, 6020, 7460, 7461
Nickel	6010, 6020, 7520
Semi Volatile Metals	
Cadmium	6010, 6020, 7130, 7131
Lead	6010, 6020, 7420, 7421
Selenium	6010, 6020, 7740, 7741
High Volatile Metals	
Mercury	7470, 7471

6010 method : atomic emission spectroscopy (inductively coupled plasma)
6020 method : mass spectrometry
7000 series methods : atomic absorption spectroscopy (furnace, flame, hydride, cold vapor)

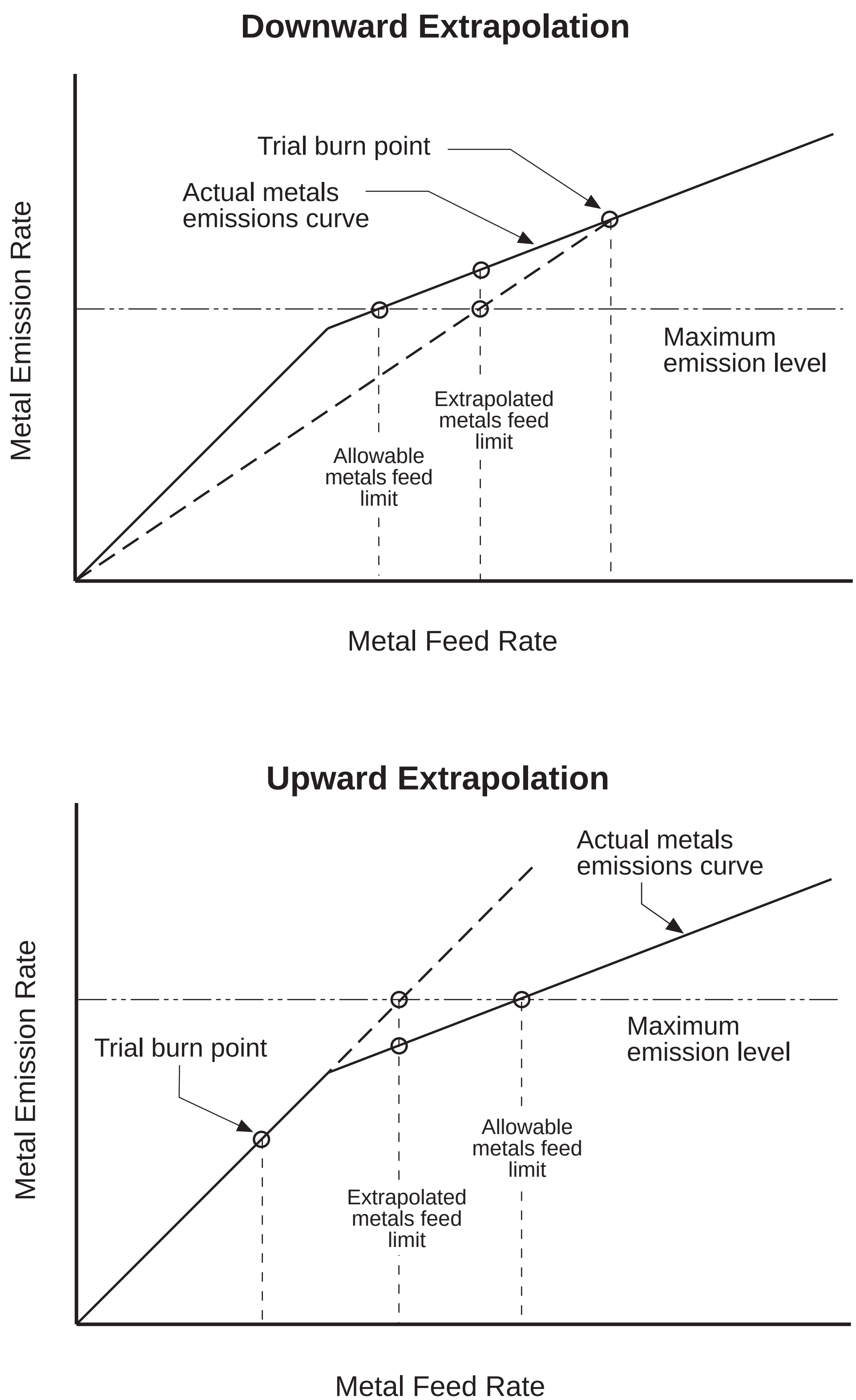


Figure 6-1. Basis for extrapolation guidance.

CHAPTER 7

OPERATING PARAMETER LIMITS TO CONTROL CHLORINE

System operating parameter monitoring and control options for assuring continuous control of chlorine emissions are discussed, including limits on: (1) combustor operating parameters including feedstream chlorine and caustic feedrates; and (2) chlorine air pollution control device (e.g., dry and wet scrubbers) operating parameters. Operating parameter requirements for assuring control of chlorine are summarized in Table 7-1.

Alternatively and preferably, both hydrogen chloride (HCl) and chlorine gas (Cl_2) (or possibly HCl alone in certain cases) continuous emissions monitors may be used as a direct indicator of total chlorine emissions, as discussed in Chapter 12.

7.1 COMBUSTOR OPERATING PARAMETERS

Chlorine feedrate -- Chlorine emissions rates generally increase with increasing chlorine feedrate. Thus a limit on the maximum feedrate of chlorine is required. The limit is based on the total chlorine contained in all feedstreams fed during the comprehensive performance test. This includes both organic and inorganic chlorine sources. Feedrate is determined by analysis of chlorine concentrations in individual feedstreams and feedstream feedrate measurements. Feedrate limit averaging is required on a 12-hour rolling average period, similar to the metals feedrate limits discussed in Chapters 5 and 6. The limit is based on the average of the individual test run averages from each run of the pertinent test condition. Feedstream chlorine and feedrate measurement methods and requirements are similar to those discussed previously in the PM (ash) Chapter 4, and Hg and LVM and SVM Chapters 5 and 6.

Caustic feedrate -- Certain feed constituents may act to control chlorine flue gas emissions (e.g., feed content of caustics such as calcium, sodium, or potassium). Thus a limit on the minimum feedrate of these chlorine controlling parameters may be appropriate. However, this limit is not recommended in general because in practice, chlorine control is primarily based on chlorine feedrate control and the use of an air pollution control device. In site-specific cases where it is determined that the waste and/or other feedstream compositions can significantly influence chlorine control, and they may be expected to vary, this limit may be appropriate. Note that although limits are not generally set on caustic feedrates in feedstreams to the combustor, as discussed below, limits are established on caustic feedrates to air pollution control devices used for chlorine control.

7.2 AIR POLLUTION CONTROL DEVICES

7.2.1 Dry and Spray Dryer Scrubbers

Dry and spray-dry scrubbing performance is impacted primarily by caustic feedrate, parameters influencing caustic-to-gas mixing, caustic type and specifications, and temperature at location of injection.

Caustic feed rate -- A limit on minimum caustic injection rate is required.

Rationale -- Increased levels of caustic injection lead to increased levels of acid gas control. Ideally compliance should be based on maintaining a minimum ratio of the caustic to that of the flue gas acid content (including HCl, HF, SO_2, etc.). However this is not possible without either very detailed and accurate waste knowledge or a continuous HCl (and SO_2) monitor. Thus, to be conservative, and ensure that adequate chlorine control is being achieved (similar to that demonstrated in the successful comprehensive performance test), a limit on minimum caustic injection rate is set.

Note that the injection rate refers to the instantaneous feed of caustic that is being sprayed into the flue gas duct or dedicated dry scrubbing vessel. It does not refer to the potential batch addition of caustic into the caustic holding silo vessels.

Limit compliance period and basis -- The minimum limit is based on a 1-hour rolling average period. It is set based on the average of the individual test run averages of the comprehensive performance test demonstrations.

Measurement techniques -- Feedrate measurement techniques are similar to those discussed in Chapter 3 for carbon injection.

Caustic type and specifications -- Caustic specifications such as chemical properties (e.g., composition, use of additives or enhancers) and physical properties (e.g., particle size, specific surface area, pore size) can significantly affect performance. Thus, the caustic that is used in continuing everyday operations must be shown to have similar or superior performance characteristics compared with that used in the comprehensive performance test.

One compliance option is to limit the brand and type of caustic used during everyday operations to exactly what was used in the comprehensive compliance testing demonstration.

Alternatively, it may be desired to have flexibility in using different brands and/or types of caustic in everyday operation compared with that used in comprehensive compliance testing. If this is required, the comprehensive performance test plan must document appropriate performance characteristics of the caustic that is used in the performance test. These proposed characteristics will be reviewed and approved as part of the comprehensive performance test plan approval by the appropriate Agencies. These characteristics will be used as the basis for caustic-type changes. The source must document in the written operating record that the caustic that is being used is adequate (i.e., that it meets the specifications of that used in the compliance testing). For caustics that are significantly different from that used in the performance testing (such as caustics from a new source or vendor) limited retesting and/or information submittals to demonstrate the performance capabilities of the new caustic may be needed. Note that these requirements are identical to those discussed for carbon adsorption and inhibitors in Chapter 3 (which discusses requirements for PCDD/PCDF control operating parameters).

<u>Carrier flowrate or nozzle pressure drop</u> -- A limit on minimum caustic carrier flowrate is required. Caustic injection nozzle pressure drop may also be used as an indicator of adequate carrier gas flowrate.

Rationale -- Caustic particles need to be properly fluidized in the transfer lines so that they do not agglomerate prior to injection. Also, caustic must be injected with adequate force to ensure proper flue gas duct coverage (sufficient caustic penetration into the flue gas).

Limit compliance period and basis -- The limit is set on a 1-hour rolling average period. The limit is set based on system/equipment designer and/or manufacturer specifications.

Measurement techniques -- Measurement techniques for flowrate and pressure drop are discussed in Chapters 3 and 10.

<u>Caustic injection temperature</u> -- Caustic capture efficiency of acid gases is a function of flue gas temperature at injection location, as well as the temperature of the APCD used to capture the used caustic. Capture efficiency tends to increase with decreasing temperature. A limit on

maximum air pollution control device temperature, set for both metals and PCDD/PCDF control purposes, is sufficient to ensure this parameter is within an adequate range.

Caustic recycling rate -- “Used” caustic (injected and caught in a particulate matter control device) may be recycled for additional use back into the process. For these system arrangements, it may be appropriate to set a limit on the maximum caustic reuse rate or the minimum new fresh caustic addition rate, similar to that discussed for carbon injection in Chapter 3.

7.2.2 Wet Scrubbers

As discussed in Chapter 4 for PM control, wet scrubbers that are used for chlorine control are generally of two main types:

- “Low energy” wet scrubbers that are highly effective for controlling chlorine emissions include types such as packed beds (including “ionizing” wet scrubbers), plate tray, and “froth” scrubbers. Also crude scrubbers such as spray (“rain”) towers are also used when less efficient control is adequate. These scrubbers operate by contacting the flue gas with the scrubber liquid stream.

- “High energy” wet scrubbers such as venturi, collision, and free-jet types can efficiently control chlorine, as well as PM. These scrubbers rely on atomized liquid droplets to collect and control PM and acid gases.

For acid gas control, general wet scrubber parameters, including scrubber liquid pH, liquid-to-gas ratio, scrubber pressure drop, and liquid feed pressure, may be used for assuring control device performance. Note that specific requirements for low and high energy scrubbers are differentiated when appropriate. When not mentioned, requirements apply to both low and high energy scrubbers.

Liquid pH -- A limit on the minimum pH of the scrubber liquid, at either the scrubber inlet or the scrubber outlet, is required for all types of wet scrubbers.

Rationale -- At lower pH levels (more acidic), scrubbing liquids have decreased acid gas solubility (especially for Cl_2). This adversely affects chlorine capture performance. Additionally, the pH should be maintained to assure that the scrubbing liquid has adequate capacity to remove acid gases (i.e., the pH of the scrubber liquor should be limited to assure that the scrubber is not being overloaded with acid). Effluent liquid pH level information can also be used for effective handling of the waste liquid. The pH is controlled by addition of caustic materials to the liquid prior to introduction into the scrubber unit or by increasing liquid blowdown (with a corresponding increase in liquid fresh makeup water).

Limit compliance period and basis -- The minimum limit is complied with on a 1-hour rolling average period basis. It is set based on the average of the individual test condition averages from the comprehensive performance test demonstration.

Measurement techniques -- The pH is monitored with a continuous liquid pH meter.

Liquid-to-gas ratio -- A limit on minimum liquid-to-gas ratio is required for all scrubber types.

Rationale -- A limit on liquid-to-gas ratio is set is to ensure proper wetting of scrubber internal packings or trays and/or to facilitate sufficient liquid and gas contacting. Liquid-to-gas ratio is maintained by adjusting the liquid injection rate and/or flue gas flowrate.

Limit compliance period and basis -- The minimum limit is set on a 1-hour rolling period. It is based on the average of the individual test run averages from the comprehensive performance test demonstrations

Note that for this and other "normalized" parameters which are a function of two independent operating parameters (not measured directly by one measurement technique), it may be adequate to set and comply with individual limits on each parameter, and not the ratio. Specifically, the flue gas flowrate is limited to a maximum level for various other purposes. Thus, a single limit on the minimum liquid flowrate is adequate as long a corresponding maximum limit is met on the flue gas flowrate through the scrubber. The liquid-to-gas ratio will always be higher than the performance test level as long as both a minimum liquid rate and maximum gas flow rate are being maintained because both increased liquid flow rate and decreased gas flow rates will result in a higher liquid-to-gas ratio.

Measurement techniques -- Liquid-to-gas ratio is determined by measurement of liquid injection rate and flue gas flowrate. Measurement techniques for both of these parameters are discussed in Chapter 10.

Pressure drop -- Pressure drop requirements are based on determination of whether the scrubber is considered as high or low energy design, as discussed above and in Chapter 4.

High energy scrubbers -- Pressure drop across "high energy" scrubber types is important in assuring scrubber performance. Increasing pressure drop for high energy scrubbers corresponds to increasing control performance, as discussed for wet scrubbers in the PM control Chapter 4. Averaging time (1-hour rolling average), basis (average of comprehensive performance test run averages), and monitoring methods are discussed in Chapter 4.

Low energy scrubbers -- For many "low energy" scrubbers, pressure drop is not generally a significant indicator of system performance. For example, for systems such as spray towers without internal packings or trays, pressure drop across the device is not expected to vary, and has little to no impact on performance. Alternatively, for packed beds and tray type scrubbers, pressure drop may be a secondary indicator of system performance, indicative to some degree of gas/liquid mixing. Thus, generally, for low energy wet scrubbers, a limit on minimum wet scrubber pressure drop is set based on manufacturer specifications. The limit must be included in a reviewed and approved performance test plan. It is complied with on a 1-hour rolling average period. A limit may not be appropriate for certain site-specific scrubber designs and arrangements. In these cases, the source may petition the Agency under Section 63.1209(g) for a waiver to the pressure drop limit.

Liquid feed pressure -- Liquid feed pressure requirements are based on scrubber system design and operation. Liquid feed pressure is required for those scrubbers which rely on liquid feed pressure for atomization of scrubber liquid, and effective chlorine control.

Low energy scrubbers -- A minimum limit on liquid feed pressure is required for low energy scrubbers. The limit is based on a 1-hour rolling average, and set from manufacturer/designer specifications as specified in an Agency reviewed and approved test plan. This limit is especially appropriate for scrubbers such as spray towers. For certain low energy designs, such as packed bed scrubbers, this limit may not be appropriate. For these cases, the source can petition to waive the liquid feed pressure requirement under Section 63.1209(g).

High energy scrubbers -- A minimum liquid feed pressure is not required for most high energy scrubbers. For certain scrubber designs, on a site-specific basis, the permitting official may require a limit under Section 63.1209(g) when it is determined to be important to scrubber liquid atomization and acid gas control.

TABLE 7-1. SUMMARY OF HYDROCHLORIC ACID/CHLORINE GAS MONITORING REQUIREMENTS

Control Technique	Compliance Using	Limits From	Averaging Period	How Limit Is Established
Limit on Maximum Chlorine Feedrate	Sampling and analysis of feedstreams[1] for chlorine (organic and inorganic) and a continuous monitoring system (CMS) for feedstream flowrate	Comprehensive performance test	12-hour	Avg of the test run averages
Wet Scrubber	CMS for maximum flue gas flowrate or kiln production rate	Comprehensive performance test	1-hour	Avg of the maximum hourly rolling averages for each run
	High energy scrubbers: CMS for minimum pressure drop across scrubber	Comprehensive performance test	1-hour	Avg of the test run averages
	Low energy scrubbers: CMS for minimum pressure drop across scrubber	Manufacturer specifications	1-hour	n/a
	Low energy scrubbers: CMS for minimum liquid feed pressure	Manufacturer specifications	1-hour	n/a
	CMS for minimum liquid pH	Comprehensive performance test	1-hour	Avg of the test run averages
	CMS for limit on minimum scrubber liquid flowrate or CMS for limit on minimum liquid/gas ratio	Comprehensive performance test	1-hour	Avg of the test run averages
Dry Scrubber[2]	CMS for minimum sorbent feedrate	Comprehensive performance test	1-hour	Avg of the test run averages
	CMS for minimum carrier fluid flowrate or nozzle pressure drop	Manufacturer specification	1-hour	n/a
	Identification of sorbent brand and type or adsorption properties	Comprehensive performance test	n/a	Same properties based on manufacturer's specifications

[1] This limit applies to all feedstreams, except natural gas, process air, and feedstreams from vapor recovery systems.

[2] A CMS for gas flowrate or kiln production rate is also required with the same provisions as required for that compliance parameter for wet scrubbers.

CHAPTER 8

OPERATING PARAMETER LIMITS TO CONTROL COMBUSTION SYSTEM LEAKS

Combustion system leaks can result from leaks from the combustion chamber(s), air pollution control equipment, or any ducting that connects them. Fugitive emissions must be controlled by one of the following:

- The combustion zone must be kept totally sealed;

- The combustion chamber pressure must be kept lower than atmospheric pressure; or

- An alternate means of control (approved by the Administrator) must provide fugitive emissions control that is equivalent to maintenance of combustion zone pressure lower than ambient pressure.

In the cases where a combustion zone pressure limit is maintained, compliance is required on an instantaneous basis. Unlike averaged parameters which must be sampled a minimum of once-every-15-seconds, combustion zone pressure measurements must be made continuously without integration, and no averaging period is allowed. They must be recorded constantly without interruption. Note that differential pressure transducers (typically used to measure combustion chamber pressure) are capable of providing a continuous electronic signal with response times down to 10 milliseconds.

Note that the combustion zone does not include portions of the system downstream of an ID fan, where above-ambient pressures are expected and allowable.

Some commenters have pointed out that it is possible to have below-ambient pressures in an unsealed part of the combustion system (e.g., a rotary kiln) and above-ambient pressure in a sealed part of the combustion system (e.g., a vertical secondary combustion chamber with an associated emergency vent stack). This is possible, for example, due to the "Thermal Siphon" effect caused by the buoyancy of hot gases (Kroll and Chang, 1991). It only necessary to maintain and record below-ambient pressure in those sections of the combustion system which are not totally sealed. For example, if an incinerator system includes an unsealed rotary kiln and a secondary combustion chamber that is sealed such that the only possible gas pathways out of the secondary are downstream through the air pollution control system or upstream through the rotary kiln, then the secondary can be considered "totally sealed" and it is only necessary to monitor combustion chamber pressure (and maintain it at below-ambient pressure) in the rotary kiln.

Some commenters have advanced the argument that cement kilns often have above-ambient pressure surges in the kiln hood due to a momentary oversupply of air from the clinker cooler, but that no fugitive emissions result because only cooler air is present in this above-ambient region. They maintain that it is not possible to measure the pressure in the true combustion zone and suggest that the maximum combustion zone pressure limit be replaced by a minimum ID fan power limit or a limit on the minimum differential pressure across the kiln. This is a valid concern. It is the sort of situation that the "alternative monitoring requirements" (approved by the Administrator) option allowed for under §63.1209(g) is designed to address.

CHAPTER 9

OPERATING PARAMETER LIMITS TO CONTROL EMISSIONS OF NON-DIOXIN ORGANICS

Non-dioxin organic HAPs have been shown to contribute a significant proportion of the total cancer risk for some receptors in at least one site specific risk assessment (USEPA, 1997). Non-dioxin organic HAPs can be emitted as partial breakdown byproducts of incomplete combustion (PICs) or as undestroyed HAPs fed to the combustor. In order to minimize PIC emissions, the HWC MACT standards set limits on emissions of CO and/or hydrocarbons to ensure good combustion.

This section discusses limits to control emissions of non-dioxin organics including:

- CO and HC
- Parameters for Batch-Feed Operations (not limited in final rule)

9.1 CO AND HYDROCARBONS

CO and HC flue gas levels are direct, continuously monitorable indicators of combustion efficiency. As discussed in EPA's 1997 *Draft Technical Support Document for HWC MACT Standards (NODA), Volume II: Evaluation of CO/HC and DRE* Database, CO and HC emissions have long been used as indicators of incinerator performance. Emissions of CO, HC and other organics are minimized when good mixing is achieved between the air and the fuel/organic waste and when temperatures sufficient to maintain combustion are encountered. Conversely, when mixing begins to deteriorate or when temperatures begin to go below those necessary to support complete combustion, emissions of CO will begin to rise, followed eventually by a rise in emissions of HC and other organics if the combustion conditions continue to deteriorate. Thus, CO is considered an advance indicator for organics emissions and HC is considered a direct indicator for organics emissions. In some circumstances (e.g., when waste is injected at a location where it bypasses the flame entirely or in the event of a total ignition failure) high HC/organic emissions may occur without accompanying high CO emissions.

A facility can choose to comply with either CO or hydrocarbon (HC) limits. These limits are specified in the standards; they are not set on the basis of performance testing. They must be complied with on an hourly rolling average basis (see Section 2.2.2). They must be reported on a dry volume basis, corrected to 7% O_2. If the measurement is made on a wet basis (for example, when measuring HC using a heated FID), then a moisture correction must be made. Although the moisture correction must be done continuously, the measurement of moisture (which must be done by monitoring for moisture using the methodology of 40 CFR Part 60, Appendix A, Method 4) can be performed continuously or it can be performed once during the comprehensive performance test and annually thereafter. The oxygen correction is made according to the following formula:

$$P_c = P_m \text{ x } 14/(E - Y)$$

where:

P_c = concentration of the pollutant or standard corrected to 7 percent oxygen;
P_m = measured concentration of the pollutant;
E = volume percentage of oxygen in the combustion air fed into the device, on a dry basis (normally 21 only air is fed);
Y = measured percentage of oxygen on a dry basis at the sampling point.

The term 14/(E-Y) above is the oxygen correction factor. As excess air or dilution air in the sample increases, Y (the measured percentage of oxygen at the sampling point) increases and the oxygen correction factor increases. High oxygen correction factors tend to decrease the sensitivity of the CO or HC monitor and increase the uncertainty of the measurement. For example, samples taken in the bypass duct of a cement kiln generally have high oxygen correction factors with correspondingly low sensitivities. This can be countered by spanning the instrument at a value proportionally lower than that required in the performance specification such that the site-specific span value should be the specified span value times the reciprocal of the oxygen correction factor. The rule requires such site-specific spans to be performed if the source normally has an oxygen correction factor greater than 2.

In extremely high excess air/dilution situations, as the measured oxygen approaches that of the combustion air (as Y approaches E in the above equation) the oxygen correction factor gets very large and can be inaccurate. One common situation where this may occur is startup/shutdown. In order to avoid this situation, sources must identify in their Startup Shutdown, and Malfunction Plan a projected oxygen correction factor to use during periods of startup and shutdown.

CO must be measured with a continuous monitor which meets 40 CFR Part 60, Appendix B Performance Specification 4B. HC must be measured with a continuous monitor which meets 40 CFR Part 60, Appendix B Performance Specification 8A. It must be reported as volume concentration equivalents of propane. O_2 (needed for oxygen correction) must be measured with a continuous monitor which meets 40 CFR Part 60, Appendix B Performance Specification 4B.

Performance specification 4B requires the CO monitor(s) to be spanned over two ranges (0 - 200 ppm and 0 - 3000 ppm). Performance Specification 8A requires the HC monitor(s) to be spanned over one range (0 - 100 ppm). One-minute CO averages which exceed the span of the instrument must be reported as 10,000 ppm, and one-minute HC averages which exceed the span of the instrument must be reported as 500 ppm. This is to ensure that temporary upsets (for example, as may occur in poorly managed batch-fed operations) which result in CO/HC spikes which exceed the span range of the instrument are fully and conservatively accounted for in calculation of rolling averages, and that a source does not avoid an automatic waste feed cutoff and does not come back into compliance and resume feeding waste too quickly after an AWFCO due to under-reported CO/HC spikes. The HWC MACT rule provides sources with an option of adding a third span range for CO monitors (0 - 10,000 ppm) and/or a second span range for HC monitors (0 - 500 ppm). For example, if the one-minute-average CO concentration was 4000 ppm, a source using the Method 4B high span range of 0 - 3000 would measure an out-of span value and would be required to record the concentration as 10,000 ppm; whereas a source using the optional 0 - 10,000 ppm high span range would be able to measure and record the concentration as 4,000 ppm.

Because HC is considered a more direct indicator than CO for organics emissions, and because it is possible in some circumstances (e.g., when waste is injected at a location where it bypasses the flame entirely or in the event of a total ignition failure) that high HC/organic emissions may occur without accompanying high CO emissions, sources which choose to comply with the CO limit, must also demonstrate in their comprehensive performance test that they also comply with the HC limit and must comply with operating limits associated with “good combustion practice” (see Chapter 10) set on the basis of that performance test.

CO/HC emissions from the main stack of a cement kiln often include contributions from organics in the raw materials which vaporize, and/or partially oxidize as the raw materials are heated by the counter-current combustion gas. Samples taken from bypasses (typical of short kilns) or from bypass sampling systems (available on some kilns) do not include these organics from the raw materials. Cement kilns with bypasses or bypass sampling systems must comply with CO/HC limits in the bypass rather than at the main stack; however, the HC limits are tighter (10 ppm as opposed to 20 ppm) than those for kilns without bypasses. Note that new Greenfield kilns (kilns that commenced construction or reconstruction after April 19, 1996 at a site where no cement kiln previously existed) must also meet a continuously monitored HC standard of 50 ppm or lower at the main stack.

- New Greenfield kilns with bypasses or bypass sampling systems must meet a continuously monitored HC standard of 50 ppm at the main stack in addition to the limits on the bypass.
- New Greenfield kilns without bypasses or bypass sampling systems must meet a continuously monitor HC standard of 50 ppm if they choose to comply with the 100 ppm CO standard rather than the 20 ppm HC standard.

Note that Greenfield kilns which choose to comply with CO limits rather than HC limits still have demonstrate compliance with HC limits lower than 50 ppm (20 ppm at the main stack or 10 ppm in the bypass) at the comprehensive performance test.

9.2 PARAMETERS FOR BATCH-FEED OPERATIONS

Batch-feeding (i.e., feeding containers, charges, or portions of charges discreetly to a combustor), if done improperly, can deplete the available oxygen in a combustor, potentially leading to increased emissions of CO, HC, and organic HAPs (including dioxins/furans). On April 1996, EPA proposed to set limits on certain parameters (maximum batch size, minimum batch feed interval, and minimum combustion zone oxygen concentration prior to charging) for batch feeding operations in order to prevent overcharging. In agreement with many commenters, EPA has concluded compliance with the CO or HC standard is sufficient to ensure that good combustion occurs in batch feed operations. Thus, the final rule does not set limits on the above-mentioned batch-related parameters.

However, EPA is concerned that carbon monoxide or hydrocarbon monitoring may not be adequate to ensure that good combustion practice will be maintained and that emissions standards will be met for all batch feed operations. Because oxygen depletion can occur very rapidly due to batch overcharging, when CO or HC begin to approach the standard it may be too late to apply corrective action. To address this concern, regulatory officials can impose additional operating parameter limits that may affect batch feeding operations for a specific site either using discretionary authority provided by §63.1209(g)(2) or through an enforcement action. It is anticipated that permitting officials will determine on a site-specific basis, typically during review of the initial comprehensive performance test plan and subsequent review of the comprehensive performance test results, whether limits on one or more batch feed operating parameters need to be established to ensure good combustion practices are maintained. This review should consider previous compliance history (e.g., frequency of automatic waste feed cutoffs attributable to batch feed operations that resulted in an exceedance of an operating limit or standard under RCRA regulations prior to the compliance date), together with the design and operating features of the combustor. To assist in this review, it is anticipated that permitting officials will require sources (through review and approval of the test plan) to simulate worst-case batch feed operating conditions (e.g., lowest oxygen levels, largest batch size and/or highest btu content, highest waste volatility, highest batch feeding frequency) during the comprehensive performance test when demonstrating compliance with the dioxin/furan and destruction and removal efficiency standards.

After the MACT compliance date, permitting officials will likely become aware of inefficient or unstable batch feeding operations, since a source is required to submit a report to the Administrator if it exceeds any of its operating parameter limits (such as the CO or HC standard) more than 10 times in a 60 day period. It is anticipated that permitting officials will take the opportunity to review batch feed operations and, if it is determined that batch feed operations do contribute to the frequency of exceedances, will use the authority under §63.1209(g)(2) to establish batch feed operating parameter limits.

To ensure that HC/CO spikes are fully accounted for, even in the event that the span value is exceeded, the final rule requires that HC and CO monitor measurements that exceed the span for any one-minute period are assumed to be (and tallied into the rolling average as) 500 and 10,000 ppmv, respectively. Note that the Method 8A span value of the HC CEMS is 100 ppmv and the Method 4B span value of the CO CEMS is 3,000 ppmv, although a source may elect to continuously monitor HC/CO over an expanded range.

CHAPTER 10

OPERATING PARAMETER LIMITS TO CONTROL DESTRUCTION AND REMOVAL EFFICIENCY

In order to control emissions of organic HAPs, a source must comply with operating limits established under conditions demonstrated to result in DREs of at least 99.99% (99.9999% for sources burning listed dioxin-contaminated or PCB-contaminated wastes). DRE is defined as:

$$DRE = [1 - (W_{out} / W_{in})] \times 100\%$$

where:

W_{in} = mass feedrate of one principal organic hazardous constituent (POHC) in a waste feedstream; and

W_{out} = mass emission rate of the same POHC present in exhaust emissions prior to release to the atmosphere

One or more POHCs must be selected from the list of hazardous air pollutants established by 42 U.S.C. 7412(b)(1), excluding caprolactam. POHC selection should be based on the degree of difficulty of incineration of the organic constituents in the waste and on their concentration or mass in the waste feed, considering the results of waste analyses or other data and information.

Measurements for DRE testing will not be further addressed here because they are treated in detail in other documents including:

- U.S. EPA, “Test Methods for Evaluating Solid Wastes: Physical/Chemical Methods, SW-846, Third Edition,” U.S. EPA Office of Solid Waste and Emergency Response, November 1986.
- U.S. EPA, “Guidance on Setting Permit Conditions and Reporting Trial Burn Results, Volume II of the Hazardous Waste Incineration Guidance Series,” U.S. EPA Office of Solid Waste and Emergency Response, Washington, DC, EPA/625/6-89/019, January 1989.

With the exception of sources that feed hazardous waste at a location in the combustion system other than the normal flame zone and sources that modify their operations such that DRE is affected, the DRE test only has to be conducted (and the resulting operating limits only have to be set) one time, provided the source has not changed design, operation, and/or maintenance practices in a way that may adversely affect its ability to achieve the DRE standard. It can be taken from a previous RCRA DRE test (so long as the appropriate measurements were taken, the standards were met, and the test was conducted within the last 5 years), or it can be conducted during the initial comprehensive performance test. Sources that feed hazardous waste at a location in the combustion system other than the normal flame zone must conduct a DRE test at every comprehensive performance test.

The following operating parameters are associated with "good combustion practice" and have limits established in the DRE test:

- Minimum combustion chamber temperature.
- Maximum flue gas flowrate or production rate.
- Maximum hazardous waste feedrate.
- Operation of waste firing system.

These parameters are also listed in Table 10-1. Note that the parameters listed above are also dioxin-related parameters for which limits must be set in the comprehensive performance test. If the DRE test is conducted separately from the comprehensive performance test, the more stringent limits take precedence. In order to avoid ratcheting down from previously established limits, a facility will be allowed to exceed its limits for DRE-related parameters in subsequent comprehensive performance tests.

<u>Minimum combustion chamber temperature</u>. A minimum combustion chamber temperature limit is established for each combustion chamber. For cement kilns and lightweight aggregate kilns, separate temperature limits apply at each location where hazardous waste may be fired (e.g., the hot end of a cement kiln where clinker is discharged; and the cold end of a cement kiln where raw material is fed). However, recognizing that it is difficult to measure mid-kiln temperatures, kilns which fire hazardous waste at that location may use the back-end temperature as a surrogate.

Rationale — The rate of organics destruction decreases with decreasing temperature. A minimum temperature limit is established to ensure that the destruction and removal efficiency demonstrated in the DRE test is maintained in continuing operation.

Limit compliance period — One-hour rolling average minimum limits are set. Rationale for the averaging period is discussed in Chapter 2 of this document.

Limit basis — The hourly rolling average limit is set based on conditions demonstrated during the DRE test. It is set as the average of the average temperature measured in each DRE-test run. For compliance, the hourly rolling average temperature may not go below its limit.

Measurement techniques — The combustion chamber temperature measurement should be made at a location that best represents, as practicable, the bulk gas temperature in the combustion zone of that chamber. This may require some site-specific considerations, so the rule requires that the temperature measurement location be identified in the test plan and subject to approval as part of the test plan.

Combustion gas temperature is usually measured with thermocouples that are shielded from radiation sources. Calibrated optical or infrared pyrometers (which measure the temperature or radiating materials such as flames or burning beds) are also used and can be effective if the gas temperature is closely related to the temperatures of the radiating materials. It is difficult to reliably measure the combustion zone temperature, especially in some high temperature industrial kilns. Thus another sampling location within the combustion chamber can be used as an indicator of combustion zone temperature; this location must be identified in the approved test plan and must be chosen to best represent the bulk gas temperature in the combustion zone. Errors in temperature measurement can be caused by insufficient heat transfer surface, radiation from the flame, or radiation from the incinerator walls.

Temperature can be controlled by adjusting the waste feedrate, using auxiliary fuel, or by adjusting the feedrate of air or oxygen.

<u>Maximum flue gas flowrate or production rate</u>. A maximum limit is established for flue gas flowrate, or on another parameter (e.g., production rate) documented in the approved site-specific test plan as an appropriate surrogate for gas residence time.

Rationale — The extent of organics destruction increases with increasing residence time. Residence time is inversely proportional to gas flowrate. A minimum flue gas flowrate limit is established to ensure that the destruction and removal efficiency demonstrated in the DRE test is maintained in continuing operation. This limit also serves to ensure that air pollution control equipment is not overloaded leading to increases in the emissions of various HAPs.

Limit compliance period — An hourly rolling average limit is established on the maximum flue gas flowrate. Rationale for the use of this averaging period is discussed in Chapter 2 of this document.

Limit basis — The limit is set based on conditions demonstrated during the DRE test. The hourly rolling average limit is set as the average over all runs of the maximum one-hour rolling average for each run. For compliance, the hourly rolling average flue gas flowrate (or surrogate) may not go below its limit.

Measurement techniques — Flue gas flowrate can be monitored with a direct gas flowrate monitor at either the outlet of the last combustion chamber or at the stack. At the outlet of the combustion chamber, there are potential measurement problems due to high temperature, high flue gas acidity, and high particulate loading. At the stack there may be problems due to air infiltration or gas moisture content. Direct measurement techniques include pitot tube, thermal conductivity indicator, sonic flow indicator, rotating disk, or flow constrictor (e.g., baffle plate, venturi, or orifice plate) methods. Flue gas flowrate can also be measured indirectly by combustion air flowrate (not possible for induced draft combustors). Characteristics of the different measurement techniques are discussed in detail in the following documents:

- U.S. EPA, "Technical Implementation Document for EPA's Boiler and Industrial Furnace Regulations," U.S. EPA Office of Solid Waste and Emergency Response, Washington, DC, EPA/530-R-92-01, March 1992.
- U.S. EPA, "Operational Parameters for Hazardous Waste Combustion Devices," U.S. EPA Office of Research and Development, Cincinnati, OH, EPA/625/R-93/008, October 1993.

Depending on the type of system, production rate could be indicated by measurement of parameters such as raw materials feed rate, thermal input, steam production rate (for boilers), or clinker production rate (for cement kilns). The parameter selected must directly correlate with flue gas flowrate.

<u>Maximum hazardous waste feedrate</u>. A limit is established on the maximum hazardous waste feedrate limit for pumpable and nonpumpable wastes. For incinerators, hazardous waste feedrate limits must be established for each combustion chamber. For cement kilns and lightweight aggregate kilns, hazardous waste feedrate limits must be established for each location where waste is fed (e.g., the hot end where clinker is discharged; mid-kiln; the upper end where raw material is fed, and/or the preheater/precalciner of a cement kiln).

Rationale — An increase in waste feedrate without a corresponding increase in combustion air can cause inefficient combustion that may lead to incomplete destruction of organic hazardous air pollutants. A maximum hazardous waste feedrate limit is established to ensure that the destruction and removal efficiency demonstrated in the DRE test is maintained in continuing operation. Separate feedrate limits are required for pumpable and nonpumpable wastes because pumpable wastes are often more easily volatilized and thus can more rapidly deplete available oxygen leading to inefficient combustion and incomplete destruction of organic hazardous air pollutants. Separate feedrate limits are required for each combustion chamber (incinerators) or each feed location (cement kilns and lightweight aggregate kilns) because the oxygen depletion due to overfeeding hazardous waste can be a localized phenomenon.

Limit compliance period — An hourly rolling average limit is established on the maximum hazardous waste feedrates listed above. Rationale for the use of this averaging period is discussed in Chapter 2 of this document.

Limit basis — The limit is set based on conditions demonstrated during the DRE test. The hourly rolling average limit is set as the average over all runs of the maximum one-hour rolling average for each run. For compliance, the hourly rolling average hazardous waste feedrate may not go below its limit.

Measurement techniques — Solid and sludge feedrates can be measured with a variety of techniques including stationary weighing systems (batch scales), conveyor weighing systems (continuous method), volumetric methods (such as auger rotational speeds), level indicators, momentum flowmeters, and nuclear absorption methods. Liquid feedrates can be measured using techniques such as rotameters, orifice meters, flow tube meters, turbine meters, vortex shedding meters, positive displacement meters, and mass flowmeters. Characteristics of the different measurement techniques are discussed in detail in the following documents:

- U.S. EPA, "Technical Implementation Document for EPA's Boiler and Industrial Furnace Regulations," U.S. EPA Office of Solid Waste and Emergency Response, Washington, DC, EPA/530-R-92-01, March 1992.
- U.S. EPA, "Operational Parameters for Hazardous Waste Combustion Devices," U.S. EPA Office of Research and Development, Cincinnati, OH, EPA/625/R-93/008, October 1993.

<u>Operation of waste firing system</u>. To ensure that the waste firing system operates properly, limits must be set on the operation of the waste firing system. Because waste firing systems can vary significantly, the HWC MACT rule does not specify which parameters must be limited nor how the

limits must be set. Rather, sources must recommend in the comprehensive performance test plan (submitted for review and approval) operating parameters, limits, and monitoring approaches to ensure that each hazardous waste firing system continues to operate as efficiently as demonstrated during the comprehensive performance test

For example, HWCs that utilize liquid injection will likely need to establish limits on either the minimum firing nozzle pressure or on the maximum liquid waste viscosity. For pressure atomizers, the pressure of concern is the pressure of the liquid waste. For twin -fluid atomizers, the pressure of concern is that of the assist fluid (typically steam or air). Pressure measurements are typically made with a pressure transducer. Viscosity can be measured by a viscometer. At least two such devices, based on rotary-measurement and piston-driven principles, are commercially available. Note that viscosity is a function of temperature. The facility would need to document in its test plan how it will measure and continuously comply with the viscosity limit. One example might be to develop a correlation between temperature and viscosity for a particular waste type and to use the temperature of the waste at the nozzle as a surrogate for viscosity.

TABLE 10-1. SUMMARY OF DRE MONITORING REQUIREMENTS

Control Technique	Compliance Using	Limits From	Averaging Period	How Limit Is Established
Good Combustion Practices	CMS for maximum waste feedrates for pumpable and total wastes for each feed system	DRE test	1-hour	Avg of the maximum hourly rolling averages for each run
	CMS for minimum gas temperature for each combustion chamber	DRE test	1-hour	Avg of the test run averages
	CMS for maximum gas flowrate or kiln production rate	DRE test	1-hour	Avg of the maximum hourly rolling averages for each run
	Monitoring of parameters recommended by the source to maintain operation of each hazardous waste firing system[1]	Based on source recommendation	To be determined case-by-case	To be determined case-by-case

[1]You must recommend operating parameters, monitoring approaches, and limits in the comprehensive performance test plan to maintain operation of each hazardous waste firing system.

CHAPTER 11

AUTOMATIC WASTE FEED CUTOFF REQUIREMENTS

On the compliance date, automatic waste feed cutoffs (AWFCOs) are required when certain parameters exceed their operating limits. An AWFCO must be interlocked with the parameter of concern, and it must immediately stop the flow of hazardous waste feed to the combustor.

AWFCO parameters include:

- CEMS-monitored emission standards
- All applicable feedrate limits (e.g., hazardous waste, pumpable LVM metals, total SVM and LVM metals)
- Minimum combustion chamber temperature (each chamber)
- Maximum temperature at the inlet to the initial dry PM control device
- Maximum combustion chamber pressure (if used to control combustion system leaks)
- Maximum flue gas flowrate (or production rate)
- Limits on operating parameters of the emission control equipment (e.g., carbon injection rate)
- Failure of the Automatic Waste Feed Cut-off system.
- Whenever continuous monitoring systems (CMS) or the measurement component of the CMS registers a value beyond its rated scale.

For parameters which are a combination of continuously monitored and periodically monitored elements (e.g., metals feedrates which are calculated from the continuously monitored waste feedrate and the periodically analyzed metals concentration), the AWFCO must be interlocked with the continuously monitored parameter, or with a reduced parameter which is updated continuously as the continuously monitored parameter changes. For example, a liquid injection incinerator may have a liquid hazardous waste feedrate limit and may utilize a waste acceptance criteria that limits the allowable mercury concentration in the liquid hazardous waste. In this situation, the facility could tie the mercury feedrate limit AWFCO directly to the continuously-monitored liquid hazardous waste feedrate based on the conservative assumption that the mercury concentration in the liquid hazardous waste is at the waste acceptance criteria limit. Alternatively, if the facility has a data acquisition system which can (based on the product of the periodically input liquid hazardous waste mercury concentration and the continuously input liquid hazardous waste feedrate) calculate the liquid hazardous waste mercury feedrate each time the liquid hazardous waste feedrate is updated, the AWFCO can be tied to the liquid hazardous waste mercury feedrate.

Some sources may have unique design characteristics which make it impossible or impractical to continuously monitor all of these AWFCO parameters. In such situations, the operator is advised to request the use of alternative monitoring techniques as allowed under §63.1209(g)

In situations where there are physical constraints that prevent sources from cutting off waste fuel (or make it impractical or unsafe to do so) at the same instant in time that an exceedance of an AWFCO parameter is detected, the operator is advised to set alarm levels such that the waste feed can be cut off and/or other appropriate actions can be taken before an exceedance will occur.

Commenters have noted that an immediate and complete shutdown of hazardous waste feed could cause a perturbation resulting in an increase in HAP emissions. This is most likely to be true when the waste is the primary fuel source and is being continuously fed (as is typically true for pumpable organic hazardous wastes).

In the event of an AWFCO, the waste feed of pumpable hazardous waste may be ramped down to zero over a period of up to one minute. Note that ramping down is not allowed for nonpumpable hazardous wastes, their feeds must be immediately cut to zero in the event of an AWFCO. In addition, ramping down is not allowed for pumpable waste feeds if the automatic waste feed cutoff is triggered by an exceedance of: minimum combustion chamber temperature, maximum hazardous waste feedrate, or any hazardous waste firing system operating limits that may be established. This is because these operating conditions are fundamental to proper combustion of hazardous waste and an exceedance could quickly result in an exceedance of an emission standard.

Facilities electing to ramp down the waste feed must document ramp down procedures in their operating and maintenance plan. The procedures must specify that the ramp down begins immediately upon initiation of automatic waste feed cutoff and the procedures must prescribe a gradual, bona fide ramping down. For example, it would not be acceptable to continue feeding waste at the same rate for one minute beyond the initiation of an AWFCO, then suddenly shut it down to zero.

If an emission standard or operating limit is exceeded during the ramp down, the facility will have failed to comply with the emission standards or operating requirements of the rule.

The AWFCO system must be tested at least weekly to verify operability Test procedures and results must be documented and recorded in the operating record. If the owner/operator documents in the operating record that weekly inspections will unduly restrict or upset operations and that less frequent inspection will be adequate, AWFCO operability testing can be extended, but it must be conducted at least monthly.

After an AWFCO, combustion gases must continue to be ducted to the air pollution control system while hazardous waste remains in the combustion chamber. The AWFCO parameters must continue to be monitored during the cutoff, and the hazardous waste feed cannot not be restarted until the AWFCO parameters are back within the specified limits.

When hazardous waste no longer resides in the combustion chamber[1] (after an AWFCO or any other cessation of hazardous waste burning), a source may elect to comply with either the HWC MACT standards or with other applicable MACT standards for non hazardous waste combustors (e.g., for cement kilns, the non-waste cement kiln MACT rule, when promulgated). If such non waste MACT standards are not in effect, the source would not be subject to any MACT standards (so long as hazardous waste no longer resides in the combustion chamber), until such standards are promulgated and their compliance date arrives. Note that all sources must determine the amount of time that hazardous waste resides in the combustion chamber following a waste feed cutoff. Sources which elect to comply with alternative standards when they temporarily cease burning hazardous waste must comply with all of the notification requirements of the alternative regulation; comply with all the monitoring, record keeping and testing requirements of the alternative MACT; modify their Notice Of Compliance to include the alternative mode of operation; and make a note in the operating record that identifies the beginning and the end of each period when they are complying with the alternative MACT.

If an exceedance of a standard or operating limit occurs in conjunction with or as a result of an AWFCO, the owner or operator must investigate the cause of the AWFCO, take appropriate corrective measures to minimize future AWFCOs, and record the findings and corrective measures in the operating record. If 10 exceedances of emission standards or operating limits occur while hazardous waste remains in the combustion chamber, based on site-specific residence time determinations, in any 60 day period, the owner/operator must investigate the cause and submit a

[1]Based on the site-specific hazardous waste residence time. For a liquid-fired combustor, the hazardous waste residence time would be the gas residence time. For a combustor which burns solid hazardous wastes, the waste residence time would be the solids residence time. Note that the determination of when hazardous waste resides in the combustion chamber is not intended to include consideration of residues that collect on or adhere to combustion chamber surfaces (walls, refractory, boiler tubes, etc.).

written report within 5 calendar days of the 10th exceedance documenting the exceedances and results of the investigation and corrective measures taken. After the 10th exceedance in any 60 day period triggers the exceedance report requirement, the 60 day period and the counting of exceedances begin anew.

Note that a facility may choose to shut off its waste feed (automatically or otherwise) before an exceedance of an AWFCO parameter occurs. In such a situation, if no subsequent exceedance occurs while hazardous waste remains in the combustion chamber, then there is no exceedance, and the event is not included in the 10 in 60 day exceedance count.

CHAPTER 12

CONTINUOUS EMISSIONS MONITORING

This chapter discusses continuous emission monitoring system (CEMS) aspects of the HWC MACT rule. It summarizes the technical information compiled and developed over the last few years by EPA in evaluation of the various CEMS considered for the HWC MACT rule.

The HWC MACT rule requires the use of CEMS for compliance with the carbon monoxide (CO) or hydrocarbon (HC) standards. As discussed in Chapter 10, these surrogate standards are used for the control of non-PCDD/PCDF HAP organic products of incomplete combustion (PICs). There are considerable public and regulatory concerns about the potential risks of organic HAP PICs from HWC units. Carbon monoxide is considered an indicator of good combustion practices. Sudden increases in CO are generally indicative of poor mixing of combustion products and air or some other form of combustion upset. High CO conditions may also indicate the likelihood of the formation of PICs. HC are considered direct indicators of the relative level of PICs in the effluent gas stream. Note that emission limits for both CO and HC are standardized to 7 percent oxygen, therefore, oxygen monitors are also required. No other continuous emissions monitors are required for compliance in this rulemaking.

The rule also requires the installation of CEMS for particulate matter (PM), but does not specify an effective date for this requirement. As discussed in detail below, demonstration studies for PM CEMS have been generally very encouraging. However, EPA recognizes the current need for further development of source-specific performance requirements for PM CEMS and to resolve other outstanding technical issues prior to requiring the use of PM CEMS. Some of the issues awaiting final resolution include:

- Questions related to implementation of the particulate matter CEMS requirement (i.e., relation to all other testing, monitoring, notification, and recordkeeping);

- Relation of the particulate CEMS requirement to the PM emission standard; and

- Technical issues involving performance, maintenance and correlation of the particulate matter CEM itself.

EPA is in the process of gathering additional data to further demonstrate the performance of PM CEMS and determine appropriate MACT PM levels when PM CEMS are used for compliance. EPA has deferred the effective date of the PM-CEMS requirement pending further testing and additional rulemaking. Note that, given the development and successful implementation of PM CEMS in Europe for the past 25 years, EPA has included valuable information on the European experience with PM CEMS later in this chapter.

Mercury CEMS were also considered during the proposal stage of this rule. However, they are not required as part of this rulemaking. The EPA has completed a field demonstration for several mercury monitors at a hazardous waste burning cement kiln. Certain aspects of the field program revealed substantial problems regarding the measurement of the precision and accuracy of the mercury monitors. EPA still believes mercury monitors can and will work at some sources but does not have sufficient confidence at this time that all HWCs are conducive to the proper operation of the Hg CEMS tested. It is likely they will work well at other sources. Some success has been noted with Hg CEMS at coal-fired utility boilers. However, because there were serious deficiencies at a cement kiln, universally requiring Hg CEMS at all HWCs is not appropriate. EPA recognizes that it has not sufficiently demonstrated the viability of Hg monitors as a compliance tool at all HWC types and has not required their use.

Owners and operators may opt to petition the Administrator to use CEMS for compliance monitoring for other pollutants. These pollutants, including Hg, semivolatile metals (SVM), low volatile metals (LVM), HCl, and Cl_2, may be monitored in lieu of compliance with the corresponding operating parameter limits discussed in other chapters of this document. The mechanism and procedures for filing the petition are defined under §63.8(f), “Alternative Monitoring Methods”. For example, if a source were approved to use a continuous mercury emissions monitor to demonstrate compliance with the mercury standard, then none of the related operating parameter limits would need to be set nor would there be a requirement for manual stack testing (beyond the monitor calibration testing).

This chapter presents the background studies conducted by EPA to investigate the viability of additional instrumentation for continuous emission monitoring. These areas include:

- A worldwide survey of the current state-of-the-art of CEMS for particulate matter (PM), mercury (Hg), acid gases, multi-metals, and organic compounds;

- Development of CEMS performance specifications and data quality assurance requirements;
- Summary of several government and industry-sponsored CEMS field demonstration programs;
- Summary of European experience including data collected with PM CEMS; and
- Description of Department of Energy-sponsored CEMS Projects.

12.1 CEMS SURVEYS

EPA has completed a comprehensive survey of the existing and emerging technologies presently available for continuous monitoring of various pollutants. This information is provided in Appendix A of this document. Summaries of these surveys have been provided in this subsection.

These surveys have been drawn primarily from direct communications and product literature obtained through the various vendors and technology developers. The surveys were conducted for CEMS used to measure metals, particulate matter, mercury, acid gases, and organic compounds. The objective of each survey was to identify the state-of-the-art in monitoring technology that is commercially available and/or under development. The survey was also intended to investigate the operational performance of the system as well as to identify the advantages and disadvantages of the systems.

12.1.1 Carbon Monoxide, Hydrocarbons and Oxygen CEMS

CO, HC, and O_2 CEMS are functional, available, and have been demonstrated as suitable for compliance with emissions standards. These monitors are presently being used at most facilities to demonstrate compliance with the RCRA regulations pertaining to hazardous waste incinerators and boilers and industrial furnaces. The technology and procedures for these monitors are well established and widely accepted by industry. No other information regarding these monitors is provided in the survey.

12.1.2 Particulate Matter CEMS

Several different types of devices are currently commercially available for continuous monitoring of PM emissions, and many are installed worldwide. Use of these devices for compliance monitoring depends on correlation against manual gravimetric methods because they measure a secondary property of the particulate rather than mass. Light scattering-based devices are TÜV approved and have been used for compliance monitoring in Germany.

TÜV is a safety testing laboratory with headquarters in Germany. The approximate English translation for TÜV (Technischer Überwachungsverein) is Technical Inspection Association. Products that bear the TÜV insignia have been tested by TÜV for compliance with applicable standards for sale in the European market. TÜV Rheinland Berlin-Brandenburg is a nonprofit organization of more than 125 years which is mandated by the German government to, among other things, perform environmental testing and the certification of continuous emission monitoring systems used for environmental monitoring.

The feasibility of using PM CEMS for compliance demonstration hinges on the stability of the correlation to the manual measurements. Correlation stability for certain PM CEMS technologies could be affected when the properties of the particulate change with process conditions. The German experience indicates that, at well-controlled sources, the correlation is sufficiently stable. This has not been confirmed at hazardous waste burning facilities in the US. However, all of the available information indicates that the use of these CEMS for compliance monitoring should be feasible. Subsection 12.3 provides a more complete description of the lessons learned during PM CEMS demonstration studies.

PM CEMS are functional, available, and suitable for compliance with emissions standards. Practical implementation of these systems will be site-specific and may require an extended shakedown period to familiarize facility instrumentation personnel with the unique characteristics of the monitors as they apply to their sources. These instruments will be useful for minimizing emissions and improving overall process performance.

Presently, a limiting technical factor that must be addressed prior to the use of these systems for compliance demonstration is the determination of an equivalent PM standard. The data are not currently available to determine the appropriate MACT standard when PM CEMS are used for compliance. This study is ongoing at EPA. A PM CEMS-based standard may follow soon after this study is completed.

12.1.3 Mercury CEMS

Commercial mercury CEMS are available and already in use in several European applications. The final rule requires the routine monitoring of mercury in the waste feed or alternatively monitoring with a mercury CEMS. Several technical issues must be dealt with when selecting the waste feed monitoring approach to demonstrate compliance with the mercury emission limit, such as: variability in waste feed, non-representative sample collection, matrix interference in laboratory analyses and maintaining safe sample handling procedures. Mercury CEMS would eliminate waste feed mercury analysis problems while providing real-time emissions data.

Several different approaches to monitoring total mercury are under development. One device is commercially available and also has TÜV laboratory approval. This unit was part of the EPA demonstration study described in Section12.3.2. Several monitors have demonstrated at least the ability to measure elemental mercury and mercury salts. Since these are the major mercury species emitted, monitoring for "total" mercury appears feasible. There are several vendors actively working to develop and market a reliable instrument that can achieve the level of precision and accuracy necessary for use as a compliance tool. Mercury monitors are receiving an increased interest, especially in the utility industry where mercury emissions are a concern.

The Agency was not able to adequately demonstrate that mercury CEMS are effective compliance assurance tools at a hazardous waste burning cement kiln. The site was judged to be a reasonable worst-case for performance of these CEMS and as such, site-related issues contributed to problems encountered during the demonstration tests.

EPA is committed to the development of CEMS that measure total mercury emissions and is continuing its research efforts. EPA believes mercury monitors can and will work at most sources, however, the complexity and level of effort may be too great at this time. As the number of voluntary installations increases and vendor improvements are made, it is likely that the implementation of these devices will become more reasonable.

The current lack of data to demonstrate total mercury CEMS at a cement kiln or otherwise on a generic basis (i.e., for all sources within a category) does not mean that the technology, as currently developed, cannot be shown to work at particular sources. Consequently, the final rule provides the option of using total mercury CEMS in lieu of complying with the operating parameter limits of §63.1209(l). This option provides the advantage of real-time mercury emissions data as a tool to demonstrate compliance in contrast to intermittent waste feed analysis and annual compliance tests.

A privately-funded summary of the state-of-the-art of mercury CEMS for use at hazardous and mixed waste incineration units was provided by French (1999). The paper provided the author's viewpoint that mercury CEMS can function accurately, beneficially, and reliably at hazardous and mixed waste incinerators. The presentation included summaries for 12 different mercury CEMS technologies for facilities considering the cost, benefits, and risks of these instruments.

12.1.4 Acid Gas CEMS

Many different types of devices for monitoring HCl are currently available and installed worldwide. Several devices are TÜV-approved and used for compliance monitoring in Germany. Several have also been tested by the EPA in a demonstration program for HCl CEMS and have been found to perform satisfactorily. The feasibility of using a CEMS for compliance monitoring of HCl can thus be considered to be established.

This is not the case for monitoring of chlorine. There are several different chlorine monitoring approaches available: UV DOAS (Opsis) and mass spectrometry. Of these, only Opsis is TÜV approved, although not for HCl, and only Opsis is widely installed. Monitoring for chlorine thus appears to be feasible, but this needs to be demonstrated in the field against EPA reference methods.

12.1.5 Multi-metals CEMS

CEMS for monitoring multi-metals are currently under development. Earliest reviews indicate several technologies have shown favorable results. Although these devices are promising, by the time any of them reach and pass the demonstration phase against EPA reference methods at least another year will have passed. It is difficult to predict exactly when any system will be fully demonstrated and commercially available.

Multi-metals CEMS are known to be installed at one incinerator and have undergone demonstration studies at several other sites. One of these studies was conducted with three multi-metals monitors installed at the U.S. Department of Energy Toxic Substances Control Act (TSCA) Incinerator in Oak Ridge, TN during August-September 1997. Measurements of metals emissions from each of the monitors were compared with data from 18 reference method test runs (Method 29) using a set of performance specification criteria. Results from the statistical evaluation showed that none of the monitors provided acceptable results under all conditions for the metals of interest. (Bechtel Jacobs for DOE, 1998).

The EPA Emissions Measurement Center (EMC) is working with the U.S. Army and U.S. Navy to field-test and validate an Inductively Coupled Argon Plasma (ICAP) Continuous Emission Monitor that provides on-line measurements of numerous metals in gaseous exhaust streams. The CEM system will be tested in production incinerator environments with comparisons against the reference procedure. A military munitions incinerator in Utah and a plasma arc furnace at Norfolk, Virginia will host the validation testing during 1999.

12.1.6 Organics CEMS

A variety of approaches for simultaneously monitoring multiple organic species are under development. Of these, direct sample mass spectrometry is the most promising due to its low (sub ppb) detection limits. There are many vendors working on this approach, and at least one system is already commercially available. This system has undergone some limited field testing in both Europe and Canada, and is currently installed on three incinerators in Europe. In-stack measurement of PICs at the one to 100 ppb range has been demonstrated. However, quantitative measurement still needs to be demonstrated by comparison with EPA reference methods in a field trial in this country. In addition, there is a need for detailed PIC emission data from hazardous waste burning facilities in order to determine which species to regulate and at what levels. If demonstration of a CEMS for PIC's is successful, then there is strong potential for surrogate (e.g., chlorobenzene) monitoring for PCDD/PCDF.

12.2 PERFORMANCE SPECIFICATIONS AND DATA QUALITY ASSURANCE

EPA has already established Performance Specifications for gases presently required to be monitored on a continuous basis (CO, HC, and O_2). EPA is in the process of developing new CEMS performance specifications for other air pollutant emission species that can be monitored on a continuous real-time basis and that may be regulated under future rulemaking. EPA is also recommending a site-specific demonstration of the CEMS, using PS 2 as a guideline to determine what performance is acceptable. The numerical values of the acceptance criteria would be based on what is demonstrated to be feasible based on the site-specific demonstration. This allows the optional use of CEMS beyond those currently required as technologies become available and demonstrated.

In general, the performance specifications that have been developed have, for the purposes of consistency, followed the general form and requirements of 40 CFR Part 60, Appendix B, Performance Specification 2 for SO_2 and NO_x CEMS (PS 2). In fact, PS 2 has been used as a standard for what is, in general, the minimum performance acceptable by a CEMS for compliance purposes. These performance specifications contain information and requirements on test procedures for calibration and zero drift, calibration error (where applicable), interference tests (where applicable), relative accuracy, and response time. Recommendations for measurement location are also included.

Draft Performance Specification 11 (PS 11) for PM CEMS is an example of a specification under development for future possible application. It contains unique aspects relative to other promulgated CEMS performance specifications. The most notable aspect is that PS 11 is based on a technique of mathematically correlating PM CEMS responses to paired manual reference method measurements. This technique is referred to as the "correlation." These provisions correlate the PM CEMS responses within acceptable statistical limitations over the full range of emissions experienced by the facility. This protocol establishes the validity and quality assurance of the ensuing PM CEMS data, albeit in a different format relative to gaseous CEMS. Gaseous CEMS have available calibration gases of known concentrations to certify and assure monitor performance. Given this fundamental difference in methodology, other novel concepts and practices for evaluating and certifying monitor performance are reflected in PS 11.

All of the performance specifications, with one exception, contain a requirement that the CEMS sample continuously and have a response time less than or equal to two minutes. This is the current requirement for the CEMS required under the BIF rule. It is adopted in the new HWC rule performance specifications because hazardous waste burning facilities are characterized by transient changes in their emissions due to the variability of the feed. The objective of this requirement is to ensure that the CEMS can track these emission transients.

The exception for the two minute response time requirement applies only to batch sampling particulate CEMS. For batch PM CEMS, Draft PS 11 would require that the response time, which is the equivalent to the cycle time, be no longer than one tenth (1/10) of the averaging time of the applicable standard or no longer than fifteen (15) minutes. In addition, the delay between the end of the sampling time and reporting of the sample analysis would be no greater than three (3) minutes. Any changes in the response time following installation would be documented and maintained by the facility operator. Sampling with batch monitors would be required to be continuous except during brief pauses when the capture media, with the collected pollutant, is being moved for analysis and the next capture medium starts collecting sample. In addition, the sampling time would be no less than thirty (30) percent of the response time.

Several promulgated and draft performance specifications are discussed in the following subsections. The performance specifications that have been promulgated with this rule are included in their entirety.

Terms in the performance specifications that require definition include the following:

- <u>Relative Accuracy (RA)</u> -- RA is assessed through comparison of a CEMS response to reference method measurements. Both the CEMS and reference method measurements are made in the stack, at or near the same location.

- Calibration Error (CE) -- CE is assessed by a challenge to the entire CEMS using an NIST traceable calibration standard (equivalent to a cylinder gas audit).

- Calibration Drift (CD) -- CD is assessed by a challenge to the analyzer portion of a CEMS using a stable standard.

12.2.1 Performance Specifications

Summaries of the applicable promulgated and draft performance specifications are discussed in the following subsections. The discussion on PM monitors (draft) is provided for informational purposes only.

Carbon Monoxide

The performance specification for CO CEMS is contained in 40 CFR Part 60, Appendix B, PS 4B. It follows PS 4A very closely. Specifications taken from 40 CFR Part 266, Appendix IX, PS 2.1 (BIF rule) and stakeholders' comments have been incorporated to form PS 4B. The essential requirements are as follows:

- Instrument span is specified for each of two measurement ranges: the low-level range span is 200 ppm, and the high-level range span is 3000 ppm.

- Recorder resolution is specified as 0.5% of span.

- Zero and upscale (span) calibration drift are specified as less than 3% of span on either the high or low range.

- Relative accuracy is specified as less than 20% of the mean of the reference method measurements or 5% of the emission limit, whichever is greater.

- Calibration error must be assessed within three sub-ranges (0-20%, 30-40%, and 70-80% of span) for each of the two measurement ranges, and must be less than 5% of span. The measurement location for the CO monitor should be the same as the O_2 monitor.

- A monitor response time of less than two minutes is required.

Hydrocarbons

The performance specification for hydrocarbon (HC) CEMS is contained in 40 CFR Part 60, Appendix B, PS 8A. It is similar to PS 8. Specifications taken from 40 CFR Part 266, Appendix IX, PS 2.2 (BIF rule) and stakeholder comments have been incorporated to form PS 8A. The essential requirements are as follows:

- Instrument span is specified to be 100 ppm, as propane.

- Recorder resolution is specified as 0.5% of span.

- Calibration and zero drift are specified as less than 3% of span.

- Relative accuracy is specified as less than 20% of the mean of the reference method measurements or 5% of the emission limit, whichever is greater.

- Calibration error must be assessed within three sub-ranges (0-0.1 ppm, 30-40 ppm, and 70-80 ppm), and must be less than 5% of span.

- The HC CEMS system (all sampling components from the probe to the analyzer) must be heated in order to maintain the sample gas within a temperature range of 150 to 175°C. A response time of less than two minutes is required.

Oxygen

The performance specification for O_2 CEMS is contained in 40 CFR Part 60, Appendix B, PS 4B. The new performance specification closely follows the requirements in 40 CFR Part 266 Appendix IX, PS 2.1(BIF rules) and comments raised by several stakeholders. The key requirements are as follows:

- The span for the oxygen monitor is specified as 25%.

- The recorder resolution is to be 0.5% of the span.

- Calibration and zero drift are specified as less than 0.5% O_2.

- Relative accuracy is specified as less than 20% of the mean of the reference method measurements or 1% O_2, whichever is greater.

- Calibration error must be assessed at three ranges (0-2, 8-10 and 14-16%), and must be less than 0.5% O_2.

- A monitor response time of less than two minutes is required.

Particulate Matter

The final rule requires the installation of CEMS for particulate matter (PM), but does not specify an effective date for this requirement. It is anticipated that PM CEMS requirements will be fully defined in a future rulemaking once outstanding issues are resolved. EPA has not finalized Performance Specification 11 (PS 11) and Quality Assurance/Quality Control Procedure 2. Stakeholder comments on these documents have been reviewed and many have been incorporated into the current drafts. The Agency will make these documents available as guidance to sources that are considering the option of using a particulate matter CEMS to demonstrate and maintain compliance.

Performance Specification 11 for PM CEMS is largely based on the International Standards Organization (ISO) Particulate CEMS performance specification, 10155 (ISO 10155). However, certain PS 11 aspects are also derived from regulatory use of these monitors in Germany for more than 25 years as well as from data obtained in U.S. demonstration programs. A correlation of the CEMS against paired particulate reference method measurements is required, the statistical treatment of the correlation data is specified, and minimum acceptance requirements on the quality of the correlation relation are set. The specification requirements discussed herein represent "current thinking" and are subject to change before PS 11 is promulgated.

Given the novel and involved nature of certifying PM CEMS, the specifications cover more considerations than those for gaseous CEMS. Many of these additional concerns in PS 11 are addressed in the "shakedown" and pretest preparations modes. These periods provide time and opportunity for operators to become more familiar with the PM CEMS and to assure collection of key performance-related items. One such item is completion of the 7-day drift test. Others include observing the instrument response over the complete range of normal emissions, setting the instrument range compatible with the emission profile, and identifying reproducible operating conditions to achieve three sub-levels within the complete range for subsequent correlation testing.

In addition, the paired manual reference method data collected for the PM CEMS correlation must meet precision requirements and two forms of systematic bias check criteria to assure data quality. Zero and upscale drift check requirements are specified as less than 2% of the upscale reference value, which is between 70 and 130% of the emission limit. The monitor's measurement range is required to cover the complete range of the facility's particulate concentrations during normal operations, startup, shutdown, and excursions. Because the particulate properties that define the CEMS response may change, the range of validity of the correlation is limited to 25% more than highest measured PM CEMS concentration observed during the correlation. Further, re-correlation may be required if facility operation, hardware, or fuels/feeds significantly change particulate properties.

12.2.2 Data Quality Assurance

The quality assurance requirements for gaseous CEMS (CO, O_2, and HC) are contained in the Appendix to Subpart EEE, Part 63 -- Quality Assurance Procedures for Continuous Monitors Used for Hazardous Waste Combustors. The procedure specifies the minimum QA requirements necessary for the control and assessment of the quality of gaseous CEMS data. Each source operator must develop a QA for calibration procedures, calibration drift adjustment, preventive maintenance, reporting, audits, and corrective actions. Key terms in the data quality assurance requirements that require definition are the following:

- Relative Accuracy Test Audit (RATA) -- RATA's involve an assessment of a CEMS relative accuracy through comparison to simultaneous reference method measurements and are conducted annually. Both the CEMS and reference method measurements are made during a minimum of nine runs. The relative accuracy of the O_2 CEMS must agree within 20% of the mean reference method value or 1.0% O_2, whichever is greater. The relative accuracy of the CO CEMS must agree within 10% of the mean reference method value or 5 ppm, whichever is greater. Seven-day calibration drift requirements are used in lieu of relative accuracy requirements for HC CEMS.

- Cylinder Gas Audit (CGA) -- CGA's are a challenge to the CEMS with an audit gas of certified concentration at two points within the following ranges: 20-30% of span, and 50-60% of span. The audit gases are introduced as close to the sampling probe outlet as possible and pass through all CEM components used during normal sampling. The CGA results must agree within ±15% of the average audit value or 5 ppm, whichever is greater. The CGA is performed quarterly (except for the quarter when the RATA is completed).

  The proposed quality assurance requirements for PM CEMS are contained in 40 CFR part 60, Appendix F, Procedure 2. This is still a draft procedure and is not promulgated within this rulemaking. These proposed requirements are structured similarly to Procedure 1, although they are undergoing refinement based on stakeholder input and field experience. Key terms in the data quality assurance requirements that require definition are the following:

- Absolute Calibration Audit (ACA) -- An ACA is equivalent to the quarterly calibration error tests that are defined in the performance specifications. An ACA uses vendor-supplied audit materials to challenge the entire CEMS in order to assess accuracy and linearity at three points within the following ranges of the upscale value: 0-20%, 40-60%, and 70-100%. The ACA results must agree within ±15% of the average audit value or 7.5% of the standard, whichever is greater.

- Response Correlation Audit (RCA) -- RCA's are a check of the stability of the correlation relation, performed by comparison of the CEMS response to manual gravimetric measurements performed simultaneously. A minimum of 12 sets of reference method measurements are made over the same normal range of facility PM emissions at three sub-levels as performed in the correlation test. At least 75% of the CEMS/reference method measurements must fall within an area developed by the CEMS regression line over the correlation range and tolerance interval bounds set at ± 25% of the emission limit.

12.2.3 Reference Method 5I

In the final HWC MACT rule, EPA promulgated a new manual method for measuring particulate matter, Method 5I. The method was first proposed in the December 1997 NODA. One outgrowth of the PM CEMS demonstration tests was that significant improvements were made toward collecting low concentration Method 5 particulate measurements. Method 5I provides significant improvement in precision and accuracy of low level particulate matter measurements relative to Method 5. Consequently, although Method 5I is not a required method, it is expected that regulatory officials would prefer its use for low particulate levels in comprehensive performance test plans. If variants other than Method 5I are to be used, care must be taken to follow the same general provisions described in Method 5I to aid in minimizing measurement error. For particulate CEMS correlation tests, the provisions include paired trains with achievement of the acceptable relative standard deviation criteria and the two forms of systematic bias checks contained in draft Procedure 2 in Appendix F (Section 10). Given these provisions, the QA/QC criteria subject to Method 5I would still be met when performing CEMS correlation tests, regardless of the reference method used.

The following changes to Method 5 have been incorporated into Method 5I: (a) improved sample handling; (b) minimization of possible contamination; (c) improved sample analysis; and (d) an overall emphasis on elimination of systemic errors in measurement. Method 5i has been validated against Method 5, but since the only real difference between the two methods is the filter extraction and weighing steps, only those steps were validated. These improvements brought about significant improvements in method accuracy and precision at low particulate matter concentrations, relative to Method 5. However, none of these changes represent significant modification to the science or chemistry in the way that samples are collected or analyzed according to Reference Method 5. Therefore, a complete change or full Method 301 validation was not warranted.

Perhaps the most significant difference between Method 5 and Method 5I is the requirement for paired trains. This requirement may be achieved by running co-located (side by side in the same port) or simultaneous (different ports at the same time). Either approach has advantages and disadvantages. Co-located testing may improve method precision, while simultaneous testing may provide more representative data assuming time and spatial differences in concentrations.

This requirement serves to document precision of the method testing and is a necessary component when developing data for PM CEMS correlation. This requirement applies whether Method 5I is used to demonstrate compliance with the emission standard or to correlate a particulate matter CEMS. It is representative of the growing recognition of the importance of quality in Reference Method measurements. It is anticipated that many future methods promulgated by EPA will have a paired train component. This is required for Method 18 and recommended for Method 5G. When a source selects to use Method 5 over Method 5I to perform PM CEMS correlation testing the requirement for paired trains remains the same.

Method 5I also includes a minimum acceptable relative standard deviation between these data pairs. As discussed below, both sets of data in the pair are rejected if they exceed the acceptable relative standard deviation. Originally the acceptance criterion for Method 5I was set at 30% relative standard deviation [where RSD = (|train A- train B|)/(train A+train B)]. The criterion of 30% was based on historical Method 5 data. The decisions to lower the RSD requirement was supported by achievability during the DuPont and Lilly studies, as well as recommendations by TÜV. It was concluded that a 10% relative standard deviation for particulate matter emissions greater than or equal to 10 mg/dscm, increased linearly to 25% for concentrations down to 1 mg/dscm, is a better representation of achievable, acceptable, precise Method 5I paired data. Data obtained at concentrations lower than 1 mg/dscm have no relative standard deviation limit.

It is anticipated that Method 5I will be preferred in all cases where low concentration (i.e., below 45 mg/dscm (~0.02 gr/dscf)) measurements are required for compliance with the standard. Given that all incinerators, nearly all lightweight aggregate kilns, and some cement kilns are likely to have emissions lower than 45 mg/dscm, it is expected that Method 5I will become the method of choice for most hazardous waste combustors. It is also acknowledged that collection of sample mass greater than 45 mg is not reason to negate a Method 5I sample run. However, testing personnel are cautioned that the smaller sample filter may be prone to plugging faster than Method 5 at high concentration sources depending on the particulate characteristics. This can be addressed through filter changes or adjusted nozzle size and sample rates.

Method 5I does not allow for the blank corrections to sample results. The use of high quality acetone, pre-screened to meet minimum purity requirements, should suffice to ensure the samples are not subject to contamination from acetone. Other blanks are recommended to assist test personnel in evaluating the potential source of contamination. This requirement is consistent with many air toxic sampling and analytical procedures.

The practical quantification limit for Method 5I is 3 mg of sample with a minimum detection limit of 1 mg. The value for determining constant weight is ±0.5 mg. Therefore, it is recommended that minimum sample volumes be adjusted to obtain a target mass of at least 3 mg.

12.3 DEMONSTRATION TEST PROGRAMS

EPA sponsored several programs to investigate the viability of particulate and mercury monitors. EPA CEMS testing has proceeded in two phases. Phase I, or "preliminary"demonstration testing, has taken place in conjunction with other EPA testing originally designed to evaluate pollution control equipment performance. CEMS testing was incorporated where the opportunity was available, defined by whether or not the appropriate reference method measurements were made, whether or not space is available at the site, and whether or not the site is willing to accommodate the CEMS. In addition, vendors were asked on short notice to participate. The aim of this testing has been to find out whether instruments are available, and to obtain an initial indication of their performance. This has been accomplished by making limited comparisons with manual reference method measurements and by allowing the CEMS to operate anywhere from one week to several months. The Phase I testing also served as proof of concept tests so EPA could decide whether a full demonstration was warranted.

Phase II has consisted of formal demonstration testing designed to evaluate the CEMS in terms of all of the requirements in the draft performance specifications. The objectives have been established such that there is at least one unit available that can meet the performance specifications, and hence be used for compliance monitoring.

12.3.1 Phase I - Particulate CEMS Testing at Rollins Bridgeport

Three PM CEMS were evaluated downstream of a pilot scale wet ESP installed at the Rollins Environmental Services commercial hazardous waste incinerator in Bridgeport, NJ (EER, 1995a).

The CEMS were chosen to represent three different measurement approaches: light scattering, time dependent optical attenuation, and beta gage. The tests were carried out in March of 1995, and were performed in three stages. First, the CEMS were calibrated according to ISO 10155 using manual gravimetric measurements (EPA Method 5). Second, the CEMS were allowed to operate for a period of about two weeks. And finally, additional manual method measurements were made in order to check the stability of the original correlation.

The test site chosen was the Rollins Environmental Services hazardous waste incinerator in Bridgeport, NJ. This facility is a commercial incinerator that burns a mix of solid and liquid hazardous waste in a rotary kiln equipped with an afterburner. The flue gases are treated by an emission control system consisting of, in order, a saturator (rapid quench), packed tower absorber, high-energy venturi scrubber, and a mist eliminator. The resulting particulate emissions from this system are typically in the 20 mg/m^3 range. During the particulate CEMS evaluation a slipstream of flue gases taken downstream of the induced draft (ID) fans and the emissions control system described above was treated by a pilot scale wet electrostatic precipitator (WESP), which dropped the PM emissions to the 1 mg/m^3 level.

The PM CEMS were located downstream of the WESP but before the slipstream was returned to the main duct at a point upstream of the ID fans. The slipstream duct diameter was 30.5 cm, and consisted of sections of both flexible plastic and hard fiberglass ducting, the latter fitted with flanges for sampling and access for the CEMS. The flue gases at the measurement point were saturated with water at a temperature of about 24°C. Previous measurements showed that the particles were predominantly less than 10 µm, and a substantial fraction (50 to 80 percent) were less than 1 µm. The presence of liquid aerosols was also a possibility due to both the operation of the WESP and the venturi scrubber, and the low temperature, saturated nature of the flue gases. Because of the high variability of the waste burned, the characteristics of the PM produced were also expected to be unusually variable, and hence to provide a demanding challenge to the PM CEMS.

The three PM CEMS chosen represented measurement approaches based on light scattering, time-dependent optical attenuation, and beta particle transmission (beta gage). Each approach requires site specific correlation testing in order to relate instrument response to PM mass loading. The beta gage response is relatively independent of the properties of the particulate. However, the beta gage is an extractive system, and is heated to prevent interference due to water and to ensure a measurement of dry particulate. Thus the beta gage was tested in order to evaluate the possible biases associated with the accuracy of the correlation, losses in the sampling system, and any influence of the heating system.

The light scattering device tested was the Sick RM200. This device measures the light scattered at approximately 90 degrees by the particulate. The light beam is generated by a near infrared LED (880 nm), and the sample volume is about 100 cm^3 located 12 cm from the wall. Both the light source and the detector are located in a single unit thus requiring only one point of access to the duct. The RM200 is designed to carry out automatic zero and span checks, and provides automatic compensation for dirt on the optics (although the optics are protected by an air purge system). The RM200 is normally located directly on the duct wall, thus making an in-situ measurement. However, for application on low temperature wet systems such as the Rollins facility, the RM200 is used with a hot bypass system. A slipstream was extracted from the duct, passed through a cyclone heater, and then passed through the sample volume of the RM200. The slipstream was then returned to a flue gas duct. This system ensured the measurement of dry particulate only.

The optical scintillation device tested was the BHA Group Inc. CPM1000™. This device measures the fluctuations or scintillation in transmitted intensity of a light beam passed across the duct. The light source is a modulated LED, which allows a constant sensitivity to be maintained by adjusting the source intensity to maintain constant detector output at the modulation frequency, thus compensating for aging of the source and dirt on the windows. The CEMS response is generated by using the AC coupled output from the photo-detector, and the instrument responds to moving particulate only, not to changes in the DC level of the transmitted intensity, as in opacity monitors. This difference between monitoring opacity and scintillation accounts for the much greater sensitivity of the latter, which can be used down to PM loadings of 0.1 mg/m^3. As the CPM1000™ was mounted directly on the duct, its response was not necessarily proportional to dry particulate, but rather to particulate at stack conditions and to any liquid aerosol that might have been present.

The beta gage device tested was the Emission SA Beta 5M. This device uses a heated sampling probe to obtain an isokinetic sample (isokinetic sampling is maintained automatically). The sample is collected on a filter, which, at the end of the sampling period, is moved (using a continuous filter tape mechanism) to a measurement location between a carbon 14 beta particle source and a detector. The initial beta transmission through each blank filter (blanking) is determined before sampling begins. The sampling duration is programmable and determines the mass concentration detection limit. At high PM loadings it must be kept small enough to prevent sampling excessive amounts of particulate, and was set at two minutes for this application. Analysis and filter indexing takes six minutes, and thus a measurement is made every eight minutes (these settings were used for the testing described here). At the end of each sampling period, the probe nozzle is temporarily closed, opened, and closed again in order to re-entrain any particulate that may have deposited in the probe.

The CEMS were all operated simultaneously and continuously during the regular daytime shift (about 8 hrs per day). During the manual method runs the hours of operation were extended as necessary. The initial comparisons were conducted by making simultaneous manual method measurements at a point upstream of the CEMS (and downstream of the WESP). The measurements were made using EPA Method 5. The Method 5 runs were made as paired trains with two sampling trains simultaneously traversing the duct through two ports set at 90 degrees to each other. Three runs were made at each of three conditions designed to produce different PM loadings, for a total of nine sets of paired manual method and CEMS data. The three different conditions were obtained by varying the WESP voltage. The conditions were 1) WESP off, 2) WESP on at a low voltage (46, 48, and 52 KV), and 3) WESP on at high voltage (52 to 53 KV). No other manipulation of facility operation was made, and other than these changes to the slipstream conditions the plant operated normally during the test period.

The initial comparison measurements took place over a period of four days, and only the RM200 and CPM1000™ were in place. Over the next two weeks, exclusive of an unscheduled plant shut down, nine days of CEMS data were obtained. The Beta 5M was online for this period. During the final two days of the test period additional manual method measurements were made in order to recheck the relationship between the CEMS responses and the manual gravimetric measurements. These additional measurements consisted of four sets of runs at two conditions: low (46 KV) and high (52 KV) ESP voltage.

Performance Specification 11 was not completely developed at the time of this Phase I demonstration. The ISO Particulate CEMS performance specifications followed call for a confidence interval of less than 10% and a tolerance interval of less than 25% at the emission limit level, and a correlation coefficient of greater than 0.95. If we assume a hypothetical emission limit equal to the upper end of the correlation range of 20 mg/m^3 measured in this work, then the RM200 was very close to meeting these specifications, despite several deficiencies in the data that contributed to the fairly large confidence and tolerance intervals. These were the following. First, the low WESP voltage condition did not produce a PM loading sufficiently different from the high voltage condition. The result was that the correlations were based on two very widely spaced clusters of points. This contributed to both the very good correlation coefficient and the large confidence and tolerance intervals. Second, the very low PM loadings were difficult to measure using the manual method. Longer sampling times would improve the precision of the manual measurements (which was estimated to be responsible for half of the magnitude of the confidence interval), and thus improve the uncertainty in the correlation relations. Finally, nine data points are the minimum number that should be used for determining the correlation relation following the ISO performance specification procedure (in Germany at least 15 data points are recommended), rather than the eight points used here. Therefore, given the limitations associated with this data set, the results obtained in this study suggest that the RM200 can be successfully calibrated under these conditions (i.e., meet the performance specifications) provided that more extensive and precise manual measurements are made.

In conclusion, although the correlation data did not meet minimum requirements for three or more different ranges of particulate loading for nine or more data points, it did provide relative indicators that additional study was warranted. The primary conclusion was that PM CEMS could be successful with proper implementation. However, the results that were obtained suggest that with proper care an optical device used in conjunction with a hot bypass can be calibrated at this facility in conformance with the ISO performance specification for particulate monitors. The check on the stability of the correlation relation for the optical device was inconclusive due to the very low particulate levels at the test condition. The behavior of the three CEMS over the two-week test period indicated that, for a low temperature, saturated stack gas, it is appropriate to extract and dry a slipstream rather than attempting to make an in-situ measurement. The results obtained with the beta gage device were inconclusive, although its behavior was consistent with the other CEMS. Finally, it should be noted that all three devices functioned properly over the two-week test period with no operator intervention.

12.3.2 Phase I - Multiple Systems Testing at Lafarge Fredonia

The Phase I testing at the Lafarge Cement Co. plant in Fredonia, KS evaluated the following CEMS. For PM: the Sick RM200 and the ESC P5A, both light scattering devices. For total mercury: the Verewa total mercury monitor. For PAH: the EcoChem PAH monitor. And for PIC's: the EcoLogic CIMS-500 mass spectrometer system made by V&F. The Lafarge facility at Fredonia has an APCS consisting of an ESP. Temperature and PM loading at the sampling location in the duct immediately downstream of the ESP (upstream of the ID fan and stack) are approximately 350°F and 0.02 gr/dscf, respectively.

The analysis of the PM data from this testing indicates a stable correlation which met the performance specifications over a period of eight weeks. With the exception of the three data points at the low ESP voltage condition, all of the data fell within the tolerance interval.

The testing for the mercury and organics measurements could not provide information of sufficient quality. Several logistical field problems contributed to the poor data quality. The mass spectrometer system was late in arriving and was damaged during shipment. Although EcoLogic was able to eventually make measurements, they were not concurrent with the reference method measurements, and thus comparison will not be conclusive. Additionally, damage incurred during shipping of the instrument was suspected to affect the stability of the readings.

The PAH monitor was unsuccessful in providing any reliable data. It is suspected that residual charge in the flue gas stream generated by the pollution control device interfered with the physics of the measurement technique.

12.3.3 Phase II - PM CEMS Testing at DuPont Wilmington

A field demonstration program at a full-scale incinerator was conducted from September 1996 to May 1997. The results were presented in a draft report issued in October 1997. The data were made available for public comment in a Notice of Data Availability (NODA) issued in the Federal Register on December 30, 1997, Docket Number F-97-CS6A-FFFFF. Technical review of the data generated from this study has continued since the draft report was issued and further conclusions are presented herein.

Overall, the PM monitors demonstrated that they could be correlated with the modified method and continuously report PM emissions with an acceptable degree of reliability and data availability. Performance criteria in the draft Performance Specification 11 were determined directly from this PM monitor demonstration and EPA historical data. The success of these tests has driven EPA's consideration for PM CEMS requirements. EPA is considering additional tests at a hazardous waste incinerator, cement kiln, and an LWAK.

The Dupont program was intended to demonstrate that at least one, and preferably more, PM CEMS have acceptable performance, even at a reasonable worst-case (for PM CEMS performance relative to PS 11) facility and determine what the "worst" acceptable performance is for PM CEMS. Another key consideration of the demonstration program centers on whether the potential exists for varying facility operations over a wide range of process conditions during the program (i.e., typical, as well as worst-case, PM CEMS scenario). EPA believes that this consideration was achieved, since:

- A wide variety of burnable and aqueous wastes were fed;
- Normal operations were experienced in a random, non-reproducible format;
- Different APC operating conditions and performance levels were achieved;
- The PM concentrations were varied from 5 to 85 mg/dscm at 7% O_2;
- The PM was analyzed and it contained at least 15 different elements;

- The PM was electrostaticly-charged, a potential worst-case PM condition; and

- Testing spanned three seasons, addressing weather/seasonal concerns with long-term reliability.

Incinerator Description

The incinerator located at the Dupont Experimental Station in Wilmington, Delaware was selected as a reasonable worst-case facility to challenge multiple PM CEMS technologies over a long-term test program. For the purpose of demonstrating the capabilities and limitations of the CEMS, a worst-case exhaust gas stream would contain: high moisture (i.e., more than 20%), PM levels in the range of the proposed emission limit, and PM with wide variations in properties (such as composition, particle size distribution, density, shape, and colors). Such a facility would burn wide mixtures of waste streams (such as a corporate or commercial incinerator), and be equipped with PM air pollution control devices (APCDs).

A Nichols Monohearth incinerator is used as the primary combustion chamber. Waste is fed to this combustion chamber using a ram feeder for solid waste, a cylindrical chute for batched waste material, and a burner for liquid waste and No. 2 fuel oil. The primary combustor exhausts to a secondary combustion chamber (afterburner) that is fired by No. 2 fuel oil. The air pollution control system consists of a spray dryer, a cyclone, a reverse jet gas cooler/condenser, a variable throat venturi scrubber, a spray absorber, a chevron-type mist eliminator, a set of electrodynamic venturis, and finally a set of centrifugal droplet separators. The treated gas stream is then drawn through the induced draft fan and a series of steam heat coils before being exhausted out the stack.

PM CEMS Description

The program included evaluation of five commercially available PM CEMS based on three different principles of operation: beta attenuation (two monitors), forward light scattering (one monitor), and backward light scattering (two monitors). Five vendors participated: Environnement SA (ESA) - Beta-gage; Verewa - Beta-gage; Durag - backward scattering; Enviromental Systems Corp. (ESC) - backward-scattering; and Sigrist - forward scattering. The test program was intended to simulate the basic activities that would be encountered by an affected facility that was carrying out the tests prescribed in the performance specifications. The actual testing performed during the program exceeded the amount of testing that would be required for a typical PM CEMS industrial installation.

- <u>Light-Scattering CEMS</u> -- The light-scattering technologies can be configured as either in-situ or extractive systems. These monitors infer particulate concentration in the stack by measuring the amount of light scattered by the particulate in either the forward or backward direction. A light sensor or photometer appropriately positioned in either the forward or backward direction measures the amount of scattered light. Each CEMS is designed with an air-purge system to minimize PM accumulation on the optics. Each monitor adjusts and compensates the detector's signal for interference, such as stray light and PM accumulation on its optics. Also, the two back-scattering CEMS have automatic zero and upscale drift checks performed at programmed intervals.

  The instruments' responses are proportional to the actual in-stack PM concentration for a given set of PM characteristics (composition, density, size distribution, and index of refraction). The detection levels are near 0.5 to 1.0 mg/m^3. The forward-scattering monitor contains a heated extractive sampling system for PM measurements in water-saturated conditions. Certain instruments undergo a factory calibration to ensure the same response for a given set of PM conditions, therefore, theoretically, a monitor can be replaced with an identical model without the need for re-correlation. However, since instrument response is dependent on PM characteristics, a site-specific correlation is required to convert instrument response into units of concentration. These CEMS produce nearly continuous output. Each of the CEMS evaluated at the DuPont site has been installed on more than 100 stacks worldwide.

- <u>Beta Gage CEMS</u> -- The two beta instruments each use a heated sampling line to obtain and deliver an isokinetic or a close-to-isokinetic sample for PM measurements. The sample is collected on a filter roll. The sampling flowrate and duration are programmable, though the optimal sampling parameters depend on PM loading. After the sampling period is completed, some form of a probe purge for re-entraining PM deposits is performed. Analysis of the filter begins with determining the Beta transmission through each blank filter spot prior to sampling. After a batch sample is collected over the sampling period, an automatic filter indexing mechanism moves the loaded filter position spot to a location between the carbon-14 Beta source and a Geiger-Muller detector. Analysis of the filter takes about two minutes. The ratio between the two analyses is representative of the PM mass collected on the filter. Thus, the response of the instrument is relatively independent of the PM characteristics. These CEMS produce results concurrent with the response period. A site specific correlation is required to convert instrument response in units of PM concentration. Each beta gage CEMS has been installed on more than 100 stacks worldwide.

Manual Reference Method 5 Modification

Before testing began, the quality of the data produced by the manual reference method for this national demonstration program was recognized as one of the most critical factors in evaluating performance of the PM CEMS. Proposed Method 5I (M5I) was developed to address collection of particulate from low concentration stationary sources.

The filter handling steps in sample assembly and recovery represent the areas likely to produce the most uncertainty in Method 5 (M5) at low concentrations. To improve precision and accuracy at low PM levels, the standard M5 filter and filter holder combination was scaled down to allow both to be weighed before and after sampling without direct handling of the filter media. Preliminary field and laboratory experiments showed that the precision for all the measurements with the smaller 47-mm filter was within M5's reported precision of 10 percent. This precision was within EPA historical particulate data. These equipment modifications were incorporated into a new manual particulate procedure designated as Method 5I. Other improvements include:

- Surgical gloves must always be used when handling the filter holder assemblies; repetitive handling without protection against transfer of natural oils produced variability.

- The filter holder must be isolated from any sources of contamination; during pre- and post-test operations secured glass plugs on the filter assemblies are required.

- Teflon beakers should be used with the probe rinses to improve weighing accuracy.

- Static charge can lead to significant variations in the weighing procedures; allowances to neutralize static charges need to be implemented.

Paired M5I measurements were also taken for purposes of comparison. The paired trains were exact duplicates in design, albeit in different operation as necessitated from separate traversing of two 90°-opposed axises. A relative standard deviation statistic (RSD) was used to estimate the precision of each pair. If the RSD was unacceptably high, the pair of manual measurements is considered unreliable and is considered an outlier. This was considered necessary since M5I data serves as the standard measure for the correlation of the CEMS.

This test program substantiates two important points learned by other groups such as TÜV in Germany: (1) the exactness of the PM CEMS correlation comes back to any uncertainty in the reference method, and (2) the uncertainty in the reference method must be less than uncertainty in the CEMS.

The demonstration program results likewise showed that the improvements in M5I lead to greater sensitivity and lower variability in measuring low PM concentrations when compared to the standard M5. The comparative results shown in Table 12-1 indicate the relative standard deviation for M5 is constant at 10%, and that M5I is an improvement to M5.

Correlation Tests and Audits

Draft Performance Specification 11 (Draft PS 11) was developed and proposed by EPA to establish the framework for certifying PM CEMS in future regulations governing their formal use on HWC facilities. This specification was used to evaluate the acceptability of PM CEMS following their installation and soon thereafter. Foremost in the Draft PS 11 is site-specific testing of PM CEMS response to initially calibrate and certify performance. Such correlation tests are composed of three (3) main elements: a) operate the facility across the complete range of facility PM emissions and operating conditions; b) conduct sets of PM CEMS and manual reference method measurements simultaneously; and c) perform these tests at three or more PM concentrations for a total of 15 measurements.

Presently, there are no available synthesized means of challenging and certifying PM CEMS performance in actual use across its intended range (*e.g.*, protocol gas cylinders with low, mid, and high concentrations). Therefore, it is necessary to change and control process conditions for developing the range of PM emission levels for correlation tests. This may be accomplished by varying the waste, ash, and/or metal feed rates in order to develop a range of PM emission levels over which the correlation is conducted. Alternatively, adjusting the performance of one or more of the PM control devices may also vary PM emissions. It is recommended that the CEMS be correlated over a minimum of a three-fold variation in concentration. Performing the correlation tests at levels above the standard is an issue currently being addressed by EPA.

An important aspect in the demonstration program was the evaluation, and revision as necessary, of the Draft PS 11 requirements. These performance specifications were drafted with the understanding that some revisions in the structure or language would become necessary based on discovery in this initial attempt to implement Draft PS 11. Based on careful review of PM CEMS performance achieved during this program and in response to public comments, it was decided to modify two of three data acceptance criteria to tighter levels than originally included in Draft PS 11. The confidence interval and tolerance interval are now proposed at the same level as specified in the International Organization for Standardization (ISO) Method 10155. Table 12-2 compares the original and new revised data acceptance criteria in Draft PS 11.

Two correlations were performed under a similarly wide variety of operating conditions. The first correlation was performed during one-week periods in each of the four months between December 1996 and March 1997. These tests established the initial correlation relation between the PM CEMS and the reference method. A second correlation test was conducted in April 1997 to evaluate the stability of the respective PM CEMS correlations.

Before discussing the correlation results, two clarifications are in order concerning PM CEMS performance evaluation methodologies applied in this program and those performed by individual facilities in the future. First, for the purpose of this program, there is a total of seven data acceptance criteria used to evaluate CEMS performance, including: a) the correlation coefficient (at one level, independent of emission standard), b) three confidence interval measures (at each of the three proposed HWC emission standards -- 34, 52, and 69 mg/dscm at 7% O_2), and c) three tolerance interval measures (at each of the three proposed emission standards). In future certifications by industry, there would only be three criteria, the correlation coefficient, the confidence and tolerance intervals at the adopted emission limit. Second, since the correlation range did not always reach each of the proposed limits, then the highest reference method concentration of the correlation test is applicable for use as the relevant reference emission value upon which the evaluation of the confidence and tolerance intervals is performed. This procedure would also be applicable in future CEMS certifications.

The best fit approaches for correlating the PM CEMS and the M5I data consisted of linear relationships for three monitors -- the ESA, Verewa, and Durag -- and logarithmic relationships for the other two -- the ESC and the Sigrist. All but the Sigrist monitor were able to meet each of the seven acceptance criteria for each correlation. The Sigrist-produced results met six of the seven criteria in the first correlation, but only met four of the seven criteria in the second correlation. There are several other information areas supporting the credibility and use of PM CEMS for compliance monitoring, two of which are discussed below.

Cumulative Correlation Results

All CEMS/M5I test data produced in this program were incorporated into one set to form a cumulative data base for each monitor. It is considered necessary and consistent with the program objectives to combine all the results in a PS 11 format to evaluate the overall reproducibility of the PM CEMS data. The form of the correlation relation producing the best fit was used: namely, a linear relation for the ESA, Verewa, and Durag along with a logarithmic relation for the ESC and Sigrist. Figures 12-1 and 12-2 graphically illustrate the correlation relation regression equation (centered dashed line), confidence interval (inner pair of solid lines), and the tolerance interval (outer pair of solid lines) for the cumulative data base for the Verewa and the Sigrist, respectively. The PS 11 statistical evaluation results, shown in Table 12-3, that for each of the five monitors the:

- Correlation coefficients are uniform and only vary from 0.93 to 0.95,
- Confidence intervals are less than 6.6%, and
- A tolerance interval is less than 24.9%.

Conclusions

The PM CEMS test program was completed under a wide variety of incinerator operation and flue gas conditions over a 9-month period. Improvements in M5I have lead to greater sensitivity and reduced variability in measuring low PM concentrations than previously achieved with M5. Data produced from more than 70 paired M5I/PM CEMS tests substantiate that at least four PM CEMS devices meet the revised PS 11 data acceptance criteria.

The results from this test program demonstrate that commercially-available PM CEMS provide statistically reliable measurements of equivalent quality to those produced by M5I and of superior quality to the *status quo* approach of parameter monitoring.

However, these results also indicate that PM CEMS technologies used in a compliance assurance setting exhibit sensitivities with respect to the proposed particulate matter emission standards. EPA rules requiring their use are being developed for consideration within a framework of their statistical relationship with PM emissions, through suitable performance specifications and QA measures, and sound technical judgements.

12.3.4 Phase II - Hg CEMS at Holnam Cement

The performance evaluation of three total mercury continuous emission monitors (CEMS) was completed at Holnam Cement in Holly Hill, South Carolina. The testing followed the general procedures specified in Draft Performance Specification 12 (PS 12) for initial Relative Accuracy (RATA) and Calibration Error (CE). The results of the data show that the Mercury CEMS require further development to meet the draft PS 12 requirements for Relative Accuracy and Calibration Error at this type of facility.

Each CEM vendor has since installed upgrades and modifications in order to enhance the durability and accuracy of the CEMS systems. In addition, consideration will be given to revising draft PS 12 itself in order to provide an accurate assessment of the CEMS performance. Specifically, additional research is required for the development of mercury and mercuric chloride calibration standards, and a calibration protocol which reflects the complexities of handling mercury and mercuric chloride gases generated by permeation tubes.

Manual method tests were conducted at two locations, the stack and in a breeching duct that exhausted to the stack. The relative accuracy for each Hg CEMS (compared to manual Method 101B) is summarized in Table 12-4.

None of the mercury monitors in this demonstration could achieve the proposed relative accuracy requirement of 20 percent of the applicable standard. Other quality control checks for calibration error also failed the proposed requirements.

Based on the overall quality of the data collected, the time and expense of the data collection effort, and the general evaluation of the state of the technology, it was judged that these systems were not suitable for the proposed application. This evaluation should not be considered judgement on the overall technologies as they may be applied to other sources.

It is accurate to state that reliable data could not be collected for an extended period using these specific monitors at this specific site.

The results for CE testing with elemental mercury (Hg^0) and mercuric chloride ($HgCl_2$) are summarized in Table 12-5a and 12-5b.

The precision of Hg and $HgCl_2$ reference gas values determined by modified M101A is shown in Table 12-6.

The flue gas conditions of high particulate loading and elevated concentrations of acid gases, contributed to the operational difficulties for the mercury monitors. Other logistical issues with calibration media and the manual test methods also hindered the success of the field study.

Mercury monitoring studies have continued for other source categories. There is a significant interest in mercury monitoring, particularly in the coal-fired utility industry. Ongoing studies at varying stages of completion have been funded by the Department of Energy. Results from these studies are not yet fully available.

12.3.5 PM CEMS Testing - Eli Lilly Clinton

An extended PM CEMS demonstration test was completed in 1998 at a liquids waste incinerator operated by Eli Lilly and Company (LILLY) in Clinton, Indiana. This study was jointly funded by Lilly, the Chemical Manufacturers Associations, and the Coalition of Responsible Waste Incineration. The final results of the study have recently been issued by the sponsoring parties, although EPA has not yet had the opportunity to complete its review. However, several preliminary statements can me made based on data that has been reviewed.

The LILLY study represented the first industry-sponsored extensive study designed to evaluate the performance of PM CEMS in a saturated gas stream with water droplets. The facility is equipped with a forced-draft down-fired liquids incinerator with a quench tank and a high-pressure drop venturi scrubber. The LILLY study design was also intended to evaluate the capability of commercially available monitors in meeting the requirements of proposed PS 11. Two of the same monitors applied in the EPA study at the DuPont incinerator were also installed for the LILLY program. Both of these monitors were equipped with heated extractive sampling systems: a Sigrist KTNR extractive light scattering monitor, and an Environnement SA (ESA) Beta 5M monitor. During the course of the study, LILLY personnel observed the initial correlation test of a Sigrist monitor performed by Mr. Karl Buhne of TÜV on a LILLY hazardous waste incinerator operating in Kinsale, Ireland. Valuable lessons learned from TÜV were then transferred to the LILLY study in Indiana. The lessons led to improvements in correlation test protocol and resulted in the monitors achieving the latest PS 11 criteria for the correlation coefficient, confidence interval, and tolerance interval.

There were several valuable lessons learned during the LILLY study that contributed to the enhancement of technical detail provided in the latest revisions to PS 11. The most significant lessons learned from the LILLY experience were:

- Stipulation that the monitor and data recorder be capable of issuing and recording instrument status signals (flagged data) indicative of various operating modes (drift checks, suspect data or maintenance flags);

- The recommendation for planning at least a 60-day monitor shakedown period to become familiar with monitor operation and identify the normal range of PM concentrations;

- Following review of the normal PM CEMS range over the shakedown, the benefit of resetting monitor parameters (range, sensitivity, or sampling period) compatible with the emission profile for more accurate measurements to be made during the correlation tests and subsequently during normal facility operation;

- The need for achieving a reproducible three-fold variation in PM concentrations reflective of normal emission variability during the correlation test; and

- If situations arise preventing adequate variation in PM levels, then alternate measures must be taken to expand the emission range during the correlation test by including either: (a) low PM facility conditions (startup, lower fuel/waste feedrates); (b) zero-point PM CEMS conditions (zero sample flow, zero air, or theoretical zero); or (c) higher PM emissions by adjusting APCD performance to simulate normal, unpreventable difficulties.

As a direct result of the success of this program, LILLY is considering installing PM CEMS as process optimization tools on stacks at their incinerators.

12.3.6 Other PM CEMS Studies

It is important to note that the following four studies may or may not meet PS-11 type objectives. A summary of each of the studies is provided below.

Electric Power Research Institute (EPRI) Sponsored CAM Program

The objective of the EPRI program was to evaluate performance of the three available options for PM Compliance Assurance Monitoring (CAM) for coal-fired utility boilers. The three options include:

- PM CEMS,
- Continuous opacity monitors, and
- Predictive emission monitoring systems.

The site selected has a typical pulverized tangential-fired boiler burning a low sulfur coal controlled by an electrostatic precipitator (ESP). The ESP is of moderate size but is unusual in that it has been retrofitted with10 separately energized fields in the direction of gas flow. These ESP characteristics and relatively lenient PM emission and opacity limits made this a suitable test bed. The facility is owned by Southern Services Company and is located near Atlanta. Key aspects of the program are as follow:

- Emission measurements included PM size distribution on the ESP inlet and PM concentration with the in-stack Method 17 (47-mm glass fiber filter) on the ESP outlet.

- Four PM CEMS vendors with two types of technologies participated: Insitec and Sadata (a Japanese company), each with a laser light scattering monitor, and PCME (a British company) and BHA, each with light scintillation technology.

- One COMS was evaluated (a double-pass unit on a ~ 5 m stack diameter).

- Model(s) to characterize and correlate PM emissions with a set of facility design and operating conditions involving a number of coal/feed characteristics and ESP conditions.

The complete set of results has not been shared with EPA at this time, albeit some data are presented in a recent paper (Roberson, 1999). Although potentially useful as a CAM study, the results of this study are not directly comparable to the EPA or LILLY studies relative to PS 11 due to different objectives, protocols, and monitors. Apparently the program was not performed in agreement with important PS 11 requirements, including use of general and specific pre-test preparations, selection of PM CEMS with data flagging and drift measurement capability, application of a shakedown period to obtain the normal range of facility emissions, and conduct of correlation tests over the facility's normal emission range.

EPA Office of Research and Development Study

EPA contracted Southern Research Institute to perform a comprehensive study of particulate monitors. The results of this effort involving several different PM CEMS technologies have not been reported at this time. Apparently a series of tests were performed in the laboratory using pilot scale equipment and in the field with a full scale coal-fired utility facility operations well before PS 11 was developed. The results of the study are expected to be released later in 1999.

EPA Office of Air Quality and Planning Standards Study

EPA contracted Midwest Research Institute to perform a PM CEMS study. This effort is focused on obtaining PM CEMS facility emissions data. Trips were made to survey and evaluate candidate cement plants for suitability in a PM CEMS test program. The effort included purchasing three types of the monitors employed in the EPA study at DuPont: a Durag DR 300 in-situ light scattering monitor, and a Durag (formerly Verewa) F 904 KD Beta-gage monitor, and an Environmental Systems Corporation P5A in-situ light scattering monitor. Until recently, the effort with the monitors was limited to performing initial hookup, data logging, and nominal operation with daily drift checks in a laboratory setting.

During June 1999 three monitors were installed at a coal-fired co-generation facility located in Rocky Mount, NC. The units are presently undergoing the shakedown period.

Department of Energy (DOE) TSCA Incinerator - Oak Ridge Program

A program to evaluate three PM CEMS at the DOE Toxics Substances Control Act (TSCA) Incinerator in Oak Ridge, TN is being planned for 1999. The performance of the PM CEMS will be evaluated to determine whether the monitors can meet PS 11. The incinerator utilizes wet scrubbers for PM control which produce a saturated exhaust stream with water droplets. Thus, only CEMS designed for application in a wet stack will be considered. Three monitors will be selected, a light scattering device and two beta-gages. Given that the only light scattering device available for wet stack operation is manufactured by Sigrist, its newest CTNR model will be one of the candidates. The other candidates, both the Durag or Environment SA Beta-gage monitors, will be selected based on previous test experience from the LILLY program. Two correlation tests are planned to be performed over the course of a 5- or 6-month period. Provided successful achievement of PS 11, facility personnel will then select one of the monitors to be permanently applied for PM compliance monitoring.

12.4 EUROPEAN DATA AND EXPERIENCE WITH PM CEMS

There is a growing body of available information on the development and use of PM CEMS in Europe. The concept and practice of applying PM CEMS for compliance monitoring were originally developed in Germany in the 1960's. Since then, the science and acceptance have evolved in terms of performance capabilities as well as the number of available technologies, industrial applications, and use for compliance determination.

PM CEMS devices are commercially available, installed on stacks world wide, and used extensively for compliance purposes in several European countries. In the 1960's, the Germans took the technical lead in the development of certification procedures and the application of PM CEMS on industrial sources. The firm Technischer Uberwachungs-Verein (TÜV) of Rheinland was largely responsible for the genesis and continued development of the specifications and certification process. Since the 1960's, PM CEMS use has expanded globally, with the same German technical specification format being adapted by the International Standards Organization (ISO), the Comite Europe de Normalization (CEN), and the US EPA. Today, hundreds of TÜV-certified PM CEMS are installed across Europe. PM CEMS are also installed at facilities in Canada for uses ranging from engineering tools to compliance monitors.

12.4.1 German Development and Specifications

After a worldwide literature survey, in November 1994 EPA directed its contractor, Energy and Environmental Research Corporation (EER), to visit Germany. Its purpose of the visit was to investigate the nature of the German experience with particulate CEMS, their certification process, and their use in practice for emission compliance. This trip included meetings with Mr. Karl Buhne of TÜV-Rheinland, a CEMS vendor (Sick Optics), and a visit to the waste incineration facility owned by the City of Bonn with an installed particulate CEMS. The findings of the trip substantiated the integrity and formal use of particulate CEMS in compliance monitoring. It also represented a vital step in obtaining information on European data and experience on particulate CEMS. The trip is summarized in the document prepared by EER entitled "Final Report on Trip to Visit TÜV Rheinland," February 1995.

The Germans first investigated the feasibility of applying particulate compliance monitors under a rule set in 1964. At least one instrument, an extinction (opacity) monitor manufactured by Sick Optics, was approved in the early 1970's for use as a continuous compliance monitor for particulate emissions from correlations across a concentration range of 10 to 450 mg/m^3. Public support for stricter emission standards mandated the need for more sensitive technologies. This led to the development of light scattering and Beta-gage monitoring technologies. The first light scattering instrument TÜV-approved for PM monitoring was designed and built by the Swiss company - Sigrist Photometer, in 1984. Shortly thereafter, Durag Industries and Sick Optics offered light scattering monitors approved by the German specifications. In 1986, German emission standards were established at levels requiring detection limits in the sub-10 mg/m^3 level. This concentration, considered too low for extinction monitors, further supported the development of more sensitive monitoring technologies. Since 1986, there have been more than 100 light scattering systems approved for PM compliance monitoring in Germany. Similar specifications were developed for Beta-gages, with Verewa (recently acquired by Durag Industries) and FAG instruments receiving approval in 1990.

The most recent TÜV performance specification guidelines for PM CEMS were developed for the German Federal Environmental Agency in 1991, replacing the former specifications set in 1980. These specifications define the minimum requirements to be met by PM monitors in suitability tests and are contained in the document entitled "Calibration of Automatic Emission Measuring Instruments" Guideline 3950, prepared by Verein Deutscher Ingenieure. Suitability tests cover extensive examinations under controlled conditions in the laboratory before undergoing an endurance challenge where the instrument is installed on a typical facility. The laboratory portion of the suitability test measures the monitor's sensitivity to fluctuations in ambient temperature, fluctuations in supply voltage, stability of zero and upscale drift measurements, and several other technical criteria to confirm the monitor's fundamental durability and performance. The field endurance test portion examines the performance of paired instruments in terms of accuracy, precision, repeatability, drift, data availability, and maintenance requirements for a 3 to 6-month period. Included in the field portion are correlation tests using manual reference method measurements. Following successful completion of the suitability test, then facilities are responsible for selecting an approved monitor and performing the initial and recurring site-specific correlation tests and monitor maintenance.

12.4.2 Particulate CEMS Certifications and Data from Europe

A limited number of reports on particulate CEMS have been translated from German to English and are available to EPA for use as supplemental technical support documentation. Examples are presented below describing the information available for certifying and correlating several particulate CEMS suitable for compliance monitoring at many industrial applications. The reports cover a 25-year period from 1972 to 1997. The reported applications include asbestos, asphalt, chemical (pigments), cement, fertilizer, glass, herbicide, lead, lime, power (coal, lignite, heating oil, and mixed fuel), rock wool, soda, sugar, steel (electric arc furnaces, blast oxygen furnaces, and sintering) and waste incineration plants. This information, documented in reports on the suitability tests prepared by the testing organization (TÜV) and by Verein Deutscher Ingenieure (German engineering organization comparable to the American Society of Mechanical Engineers), are summarized below in chronological order. Tables 12-7 and 12-8 provide summaries of the German, ISO, and draft EPA specifications for particulate matter CEMS discussed herein. Based on the data in the German reports, Table 12-9 presents the correlation test results for correlation coefficient, confidence interval, and tolerance interval calculated by EPA using the equations in Performance Specification 11. These data show that the German-certified particulate monitors typically met the PS 11 data acceptance criteria by achieving, on average:

- Correlation coefficient of 0.95,
- Confidence interval of 7.3%, and
- Tolerance interval of 17%.

Recording Dust Measurements in the Cement Industry with Sick Company's RM4 Device for Measuring Smoke Density (by Karl Buhne and Ludwig Duwel of TÜV-Rheinland, circa 1972)

This paper describes the process and results of a suitability test with the Sick Company's RM4 optical extinction monitor carried out by TÜV and the German Research Institute of the Cement Industry over a several month period. Testing was performed in the laboratory to check for interference factors in line voltage and ambient temperature fluctuations as well as adjustment and reflection of the optics. The next segment of testing was conducted at a 615 ton/day capacity portland cement plant controlled by an ESP. Exit gas from a precalciner kiln and connecting drum dryer were measured by two monitors installed at the same measuring point in a 1.95 meter diameter stack. The ports for the manual reference method measurements were located adjacent to the monitors. Ample time and opportunity to adapt the monitors to the specific conditions and difficulties were afforded before testing began. Written protocols were prepared and used for all planned actions, changes, and repairs and made available to the manufacturer and regulatory agency as the test proceeded.

After the zero point and absolute calibration checks were made, correlation tests were performed over normal but distinct operations of the kiln and drum dryer. A total of 57 reference method measurements were performed across a particulate emission range of 10 - 450 mg/m^3, with the major portion being with paired trains to determine precision of the manual method data. While the correlation data for the monitors and manual measurements are not presented, there was a definite linear relationship between extinction and particulate concentration across the full emission range with a correlation coefficient above 0.99. Similarly, a correlation coefficient above 0.99 was obtained in a random analysis comparing the continuous data produced by the two monitors.

Measurement of Particulate Matter in Flowing Gases - Determination of Dust Load by Continuous Measurement of Optical Transmission (by Verein Deutscher Ingenieure 2066/Part 4, 1989)

This capsule report, drafted in German in 1980, describes the process and example results of initial certification tests with the Sick Company's RM41 and the Durag Industrie Electronik GmbH DR 280 optical extinction monitors. Both Sick and Durag are German monitor manufacturing companies. It serves as a "technical cookbook" illustrating how to install, check, and certify optical extinction monitors for use in compliance monitoring. Though brief, it is effective in emphasizing the key points of the monitor installation and certification process. The document also lists many references and support materials for more in-depth instructions. Included in the report are example data with reference tables and calculations along with forms to facilitate documentation of key certification test results. It states that field testing for suitability of these two monitors was successfully completed on combustion plants (for pit coal, lignite, heating oil, and mixed fuel), waste incinerators, asphalt plants with baghouses, and cement plants. It also reports that the monitors have been used successfully in several industries, including steel (blast plants, electro-smelters and sintering plants), lime, fertilizer, soda, sugar, and even in monitoring workshop air. It is clearly stated that these monitors are not suitable for measurement behind wet scrubbers without subsequent reheating of the exhaust gas stream.

The report presents results for an extinction monitor and manual method measurements obtained at a power plant for an example data set to perform correlation calculations. Data are presented from four operating conditions: (1) mixed fuel, (2) sootblowing, (3) pit coal, and (4) reduced particulate APCD efficiency. A total of 15 reference method measurements were performed across a particulate emission range of 55 - 135 mg/m^3. As in the case above, there was a definite linear relationship between extinction and particulate concentration across the full emission range with a correlation coefficient above 0.96.

Measurement of Particulate Matter in Flowing Gases - Determination of Dust Load by Continuous Measurement of Scattered Light (by Verein Deutscher Ingenieure 2066/Part 6, 1989)

This capsule report describes the process and example results of initial certification tests with the Model KTN and KTNR light scattering monitors manufactured by Sigrist Photometer AG of Switzerland. It serves to illustrate how to install, check, and certify optical extinction monitors for use in compliance monitoring. Though brief, it is effective in emphasizing the key points of the monitor installation and certification process while also providing references for more in-depth instructions. Included are example data with reference tables and calculations along with forms to facilitate documentation of key results. Laboratory test results checking interference-free performance from fluctuations in supply voltage, ambient temperature, and stray light are tabulated. The report states that field testing for suitability of these two monitors was successfully completed on lead smelters, secondary lead reclamation plants, electric arc furnaces, and plants processing asbestos for brake linings, each with baghouses. Also mentioned is that the monitors have been used successfully in several types of plants, including oxygen steel, color pigments, fertilizer, herbicide, glass and rock wool, waste incineration, and coal-fired steam generators. Equipped with a heated extractive sampling system, this monitor is suitable for measurement of wet gas streams produced by scrubbers.

The results for the Sigrist KTNR light scattering monitor and manual method measurements are provided for the example correlation test data set. A total of 17 reference method measurements were performed across a particulate emission range of 0.7 - 2.5 mg/m^3. As in the cases above, there was a definite linear relationship between instrument response and particulate concentration across the full emission range with a correlation coefficient of 0.92.

Performance Testing of the F-904 Beta Gauge Particulate Monitor Manufactured by Verewa GmbH (by R. Wilkes and B. Samadi of TÜV, 1990)

This is a more extensive report than the above capsule reports. Additional details are included on the process and results of initial certification tests with the Model F-904 Beta gage monitor manufactured by Verewa GmbH, a German manufacturing company recently acquired by Durag. Included is a thorough description of the monitor design, configuration, and operation. The laboratory test results for checking the monitor's performance during supply voltage and ambient temperature fluctuations are presented along with drift checks of the filter mass, sample flow and dilution air flow measurement systems. Single filter measurements were taken to verify the one-to-one relationship between the monitor response and the actual dust mass collected (weight gain) on the filter tape. The seven operational status signals from self-diagnosis are identified.

Field testing was conducted at a waste incinerator controlled by an ESP and wet scrubber. Two monitors were installed at the same measuring point (about one meter apart) in a 2 meter diameter stack. The ports for the manual reference method measurements were located adjacent to the monitors. A preliminary test phase of four weeks was afforded to assess the monitors' performance and functionality prior to the 3-month test period. Zero and upscale drift checks were made 14 times during the 5-month test period, each time meeting the ±4% drift specification. Correlation tests were performed with 12 reference method measurements across a relatively narrow emission range of 3.5 - 8.0 mg/Nm^3. Three zero-points were added to expand the range. The correlation data for the monitors and manual measurements are presented and show a linear relationship between monitor response and particulate concentration with a correlation coefficient of 0.95. Similarly, a correlation coefficient above 0.99 was obtained in a random analysis comparing the continuous data produced by the two monitors. Reliability evaluation test showed that a weekly maintenance interval is required for purging the probe and sampling line and checking preset values for the sample and dilution flowrates. In addition, the sample probe must be cleaned at least once every four weeks. This monitor is suitable for wet gas stream measurements as it is equipped with a heated extractive sampling line.

Report on the Performance Testing of the D-R 300-40 Dust Concentration Monitor Manufactured by Durag Industrie Electronik GmbH (by Karl Buhne and W. Schlomer of TÜV Rheinland, 1992)

This is also a comprehensive report prepared by TÜV. Very good detail is included in the report for the initial certification tests with the Model D-R 300-40 in-situ light scattering monitor manufactured by Durag GmbH. Included in this report is a thorough description of the monitor design specifications and operation. In addition to the usual array of laboratory test results, this report presents interesting data from injection of six industrial dusts (quartz, titanium dioxide) into a test duct at the Technical University of Munich. These data clearly documented the sensitive influence of light scattering instrument response on particle characteristics and covered the range of real emission characteristics of particulate from coal and waste burning facilities.

Field testing was conducted at a secondary lead smelter controlled by a baghouse. Two monitors were installed at the same measuring point in a 1.0 meter diameter stack during a 3-month test period. The ports for the manual reference method measurements were located adjacent to the monitors. A preliminary test phase occurred to assure the monitors' performance and functionality. Zero, dirty window, and upscale drift checks were made several times with achievement of adequate stability relative to +/- 4% drift specification. The rotary kiln operated over its normal cycles for lead charging, melting, pull-off, slag melting, and slag pull-off. Correlation tests were performed with 27 reference method measurements across a relatively narrow emission range of 0.5 - 1.9 mg/m^3 with zero-points added to expand the range. The correlation data for the monitors and manual measurements are presented and show a linear relationship between monitor response and particulate concentration with a correlation coefficient of 0.98. Reliability tests showed that a drift check is required every four hours. In addition, the sample probe must be cleaned at least once every four weeks. This monitor is not suitable for wet gas stream measurements.

Report Over the Aptitude Test of the Dust Content Equipment of the Type CPM 1001 from the Company BHA Group GmbH (by R. Wilkes of TÜV, 1997)

This is another comprehensive report prepared by TÜV. Details are included for the initial certification tests with the Model CPM 1001 in-situ cross-stack scintillation monitor manufactured by BHA GmbH. A thorough description of the monitor design specifications and operation and the usual laboratory test results are included in the report.

Field testing was conducted at a coal-fired boiler for 12 weeks and at a waste incinerating plant for six weeks. Two monitors were installed at the same measuring point in a 3.0 meter diameter stack at the boiler and in a 1.4 meter diameter stack at the incinerating plant. Correlation tests were performed with 15 reference method measurements at each facility across a range of 40 - 150 mg/m^3 for the boiler and 0.7 - 20 mg/m^3 for the incinerating plant. Reported results included the use of zero points. The correlation data for the monitors and manual measurements are presented and show a linear relationship between monitor response and particulate concentration. Tests showed that the maintenance interval is every eight days. In addition, the purge air filters must be cleaned at least once every four weeks. This monitor is not suitable for wet gas stream measurements.

Report on the Suitability Testing of the Dust Emission Measuring Instrument CTNR of the Company Sigrist-Photometer AG (by Karl Buhne and Dr. Peter Wilbring of TÜV Rheinland, 1997)

This is another comprehensive report prepared by TÜV. Details are included on the initial certification tests with the Model CTNR light scattering monitor manufactured by Sigrist. The CTNR is the successor model of the KTNR with a 10-fold increase in sensitivity. Included in the report is a thorough description of the advancements made in monitor design and operation along with the usual set of laboratory test results.

Endurance field testing was conducted at two facilities over a period of about four months. This involved testing at a waste incinerator with very low emissions for seven weeks and at a lignite-fired boiler with a flue gas desulfurization system for nine weeks. Two monitors were installed at the same measuring point at both installations. Preliminary testing occurred to assure the monitors' performance and functionality. Correlation tests were performed with 13 reference method measurements at the incinerator across a range of 0.03 - 0.38 mg/m^3 and with 15 runs at the boiler across a very narrow range of 1.8 - 2.2 mg/m^3. The incinerator range was developed over normal facility operations, soot blowing, and with dust injection upstream of the induced draft fan. The test at the boiler was conducted only during normal operations, requiring the addition of zero points to expand the range. Correlation data for the monitors and manual measurements were presented and show a linear relationship between monitor response and particulate concentration with a correlation coefficient of 0.95 or better for both installations. Reliability evaluation tests showed that the maintenance interval is every four weeks. Like the Sigrist KTNR model, the CTNR monitor is equipped with a heated sampling line and is suitable for wet gas stream measurements.

12.4.3 European Experience with Particulate CEMS

TÜV has been used as a consultant. The assistance of TÜV was sought because they have been the world-recognized experts in particulate matter CEMS and the practical aspects of developing correlations for nearly 30 years. TÜV's status as an impartial "Underwriters Laboratory"-type arbiter and that their impartiality has been demonstrated and well documented. Furthermore, TÜV's has maintained a longstanding professional relationship with the vendors and have an excellent understanding of the operating principles and how the devices can be correlated at a given facility. Appendix C documents information obtained from EPA's discussion with Dr. Wolfgang Jockel, the Leader of their Particulate CEMS group for TÜV Rheinland.

12.5 DEPARTMENT OF ENERGY-SPONSORED CEMS PROJECTS

The Department of Energy (DOE) has a vested interest in promoting and applying new CEMS technologies to provide more frequent measurements of toxic pollutants in incinerator gas streams. Previous research, development, and production operations for munitions and national defense-related projects at DOE facilities have left a legacy of radioactive and hazardous waste requiring management and disposal.

Incinerator feedstream monitoring for DOE is a big concern because their wastes are primarily mixed low-level radioactive and hazardous wastes. Analyzing these feeds is often not possible or causes a potential threat to the health of the workers doing the sampling. With improved performance, reliability, and use of CEMS, the regulatory requirements associated with feedstream monitoring would be reduced. An additional benefit is that CEMS can provide assurances to the public that mixed/hazardous waste incinerator emissions are below the emission standards on a continuous, rather than periodic basis.

DOE and EPA have a long history of cooperating together on CEMS and other projects. The Hg and Particulate CEMS Demonstration tests are examples (see Section 12.3). Other joint ventures include projects at the EPA Incineration Research Facility during which ten CEMS were tested; and projects at the DOE TSCA Incinerator (TSCAI) in Oak Ridge, TN, during which three particulate CEMS were tested (see Section 12.3.6 for DOE Particulate CEMS evaluation). DOE has independently sponsored a multi-metals CEMS and a Hg CEMS evaluation at the DOE TSCAI. In addition, DOE has sponsored several developmental CEMS technology projects which are at various stages of completion. In response to these incentives, several activities directly applicable to emerging CEMS technologies have already been performed or are underway. DOE has designated the TSCAI as a primary test unit for advanced monitoring technologies to facilitate evaluation and demonstration of newly developed CEMS. The following subsections provide brief summaries of the DOE-sponsored CEMS projects.

12.5.1 Fourier Transform Infrared (FTIR) Evaluations at TSCAI

A prototype FTIR spectrometer, developed by Argonne National Laboratory, was evaluated at the DOE TSCAI on three occasions in 1993, 1994, and 1995 to determine the feasibility of continuously monitoring organic species in incinerator emissions. The FTIR spectrometer and the long-path cell used for the field tests were specifically designed for this application. During each test, the FTIR system was connected to the exhaust gas stream by means of a 100-ft-long heated sampling line to measure emission levels in an extractive sample. The results produced showed very low emissions. General agreement was obtained between measurements of CO and CO_2 taken with the facility monitors and the FTIR. No target analytes were detected at levels above the instrument detection limits, except for methane, detected at 4 - 5 ppm.

12.5.2 Ion Trap Mass Spectrometer Evaluation at TSCAI

A field portable direct sampling ion trap mass spectrometer from Oak Ridge National Laboratory was tested over a period of several weeks at TSCAI in 1994 to determine the feasibility of monitoring semivolatile organic compounds (i.e., PCBs, dioxins/furans) in stack emissions.

Although the direct sampling ion trap mass spectrometer had been successfully applied to continuous monitoring of organic analytes in water and soil, this was the first attempt to monitor stack emissions. The study concluded that batch sampling using sorbent traps and either off-line analysis or delayed on-line analysis in a thermal desorption mode would be required to reach the detection limit for volatile and semivolatile organic compounds in the incinerator exhaust gas emissions.

12.5.3 Multiple Technology CEMS Evaluation at the EPA Incineration Research Facility

Ten prototype or developing CEMS technologies for measuring trace metal or trace organic species were evaluated at the EPA Incineration Research Facility located in Jefferson, AR in 1996. Four CEMS measured several volatile organic compounds (VOCs), one measured total particulate-bound polynuclear aromatic hydrocarbons, two measured multi-metals, and three measured Hg. A synthetic hazardous waste with a mixture of 14 trace metals and VOCs were fed to the test incinerator. The results showed the prototype nature of most approaches tested, and the clear need for these approaches to undergo further development.

12.5.4 Multi-metals CEMS Evaluation at TSCAI

A field study evaluating the performance of three candidate multi-metals monitoring techniques was performed in 1997. The three systems tested were the *TraceAIR* inductively coupled plasma atomic emission spectrometry monitor manufactured by Thermo Jarrell Ash Corporation; a laser-induced breakdown spectroscopy monitor developed by Sandia National Laboratories; and the Hazardous Element Sampling Train (HEST), developed by Cooper Environmental Services. EPA Method 29 measurements for multi-metals were made to provide reference comparisons for evaluating the performance of the monitors. Metals spiking solutions were injected into the incinerator at three different rates to create a range of emission concentrations. Results produced from the study showed that only the HEST could meet the criteria for more than half of the test conditions for the metals of interest.

12.5.5 Hg CEMS Evaluation at North Dakota Energy and Environmental Research Center

A field study evaluating the performance of three candidate Hg monitoring techniques was performed in 1997 at the North Dakota Energy and Environmental Research Center. The three systems tested were a Perkin Elmer MERCEM, the Semtech Hg 2000 monitor, and the PS Analytical Sir Galahad CEMS. The test facility used a gas containing 5000 ppm of SO 2 and 1250 ppm chloride to simulate the exhaust gas from burning high sulfur and high chlorine coal. The Ontario Hydro Method for Hg was used to provide reference comparisons for evaluating the performance of the monitors. The MERCEM produced data within 20% of the Ontario Hydro reference method.

12.5.6 Hg CEMS Evaluation at TSCAI

A Perkin Elmer MERCEM monitor was evaluated at the DOE TSCAI in 1998 to determine the feasibility of continuously monitoring mercury species in incinerator emissions. EPA Method 101B measurements for Hg were made to provide reference comparisons for evaluating the performance of the monitor. Two different waste types were fed to the incinerator to produce two different Hg concentrations in the exhaust gas. The relative standard deviation of the MERCEM results was as good or better than Method 101B, although the MERCEM gave consistently higher results than the reference method. These results indicated a bias that may be corrected using a site-specific correlation factor, similar to the approach used for particulate CEMS.

12.5.7 Other DOE-sponsored CEMS Projects

Other DOE-sponsored CEMS projects include:

- Multi-metals CEMS Evaluation at the EPA/RTP Pilot Incinerator in 1997,
- Development of a Real-Time Jet-REMPI Based Dioxin/Furan Monitor,
- Development of a Laser-Induced Spectroscopy for Multi-metals Monitoring, and
- Development of a Atmospheric Microwave-Plasma Approach for Multi-metals Monitoring.

12.6 BIBLIOGRAPHY OF EUROPEAN AND OTHER AVAILABLE LITERATURE ON PARTICULATE AND OTHER POLLUTANT CEMS TECHNOLOGIES

I. *German Particulate Performance Certification Reports (Comprehensive test evaluations performed both in laboratory and under field conditions over several months)*

1. Buhne, K. W. and L. Duwel (TÜV), "Recording Dust Measurements in the Cement Industry with Sick Company's RM4 Device for Measuring Smoke Density," circa 1972, 19 pp.

2. Verein Deutscher Ingenieure, “Measurement of Particulate in Flowing Gases - Determination of Dust Load by Continuous Measurement of Optical Transmission - VDI 2066 Part 4,” January 1989, 23 pp. (Condensed report for the Durag Model DR 280 Optical Extinction and the Sick Model RM 41 Optical Extinction PM Monitors).

3. Verein Deutscher Ingenieure (VDI), Particulate Measurement - “Measurement of Particulate in Flowing Gases - Determination of Dust Load by Continuous Measurement of Scattered Light with the Photometer KTN - VDI 2066 Part 6,” January 1989, 27 pp. (Sigrist Model KTNR Monitor).

4. Wilkes, R. and B. Sanadi (TÜV), “Performance Testing of the Model 904 Beta-Gage Particulate Monitor Manufactured by Verewa,” 1990, 55 pp.

5. Buhne, K. W. and W. Schlomer (TÜV), “Performance Testing of the D-R 300-40 Dust Concentration Monitor Manufactured by Durag Industrie Elektronic GmBH, Hamburg, Germany,” July 1992, 50 pp.

6. TÜV, “Report over the Aptitude Test of the Dust Content Measuring Equipment of the Type CPM 1001 from the Company BHA Group GmbH,” Germany, 1997, 58 pp.

7. Buhne, K.W., and Dr. P. Wilbring (TÜV-Rheinland), “Report on the Suitability Testing of the Dust Emission Monitoring Instrument CTNR of the Company Sigrist-Photometer AG,” Cologne, Germany, August 1997, 43 pp.

II *Other Supporting and Related Literature for above* TÜV *Certifications*

8. Verein Deutscher Ingenieure (VDI), “Calibration of Automatic Emission Measuring Instruments, VDI 3950 Part 1,” 1991, 39 pp.

9. VDI, “Manual Dust Measurement in Flowing Gases - Gravimetric Determination of Dust Load - Tubular Filter Devices (40 m^3/hr) - VDI 2066 Part 3,” 1994, 16 pp.

10. VDI, “Manual Dust Measurement in Flowing Gases - Gravimetric Determination of Dust Load - Plane Filter Devices - VDI 2066 Part 7,” 1993, 20 pp.

11. ISO, “Ambient Air – Measurement of the Mass of Particulate Matter on a Filter Medium – Beta-ray Absorption Method - Draft Method ISO/DIS 10473,” 1996, 15 pp.

12. ISO, "Stationary Source Emissions – Determination of Concentration and Mass Flow Rate of Particulate in Gas-carrying Ducts – Manual Gravimetric Method 9096," 1992, 29 pp.

13. ISO, "Stationary Source Emissions – Automated Monitoring of Mass Concentration of Particulate--Performance Characteristics, Test Methods and Specifications - Method 10155," 1995, 18 pp.

III. *Other Related Materials on Particulate CEMS in U.S.*

14. Martin, Prof. Peter, "Measurement of Low Particle Concentrations with Stray Light Instruments,"Paper 93-WP-176.12P, at 86th Annual AWMA Meeting, Denver, June 1993.

15. Martin, Prof. Peter, "Comparison of Particulate Measurement Technologies," at Continuous Emission Monitoring Conference '96, Edmonton, Alberta, May 1996.

16. Baujon, A. et al., "Continuous Monitoring of Stationary Source Dust Emissions at Low Concentrations in the Sub-Milligram Range," Location and date unknown, 48 pp.

17. EER Corp, "CEMS - Final Report on Trip To Visit TÜV Rheinland, Prepared under EPA/Office of Solid Waste Contract 68-D2-0164, February 1995, 34 pp.

18. Sloss, L., "Continuous Emission Monitoring for Coal-fired Power Stations," Presented at IEA CR International Workshop, London, April 1997, 51 pp.

19. Joklik, R.G. and H. S. Rauenzahn,"Evaluation of Particulate Matter and Total Mercury Continuous Emission Monitors for Compliance Monitoring at Hazardous Waste Combustion Facilities," at 89th Annual AWMA Meeting, Nashville, TN, June 1996.

20. U.S. EPA, "Handbook - Continuous Emission Monitoring for Non-criteria Pollutants," EPA/625/R-97/001, April 1997, 159 pp.

21. U.S. EPA, "Particulate Matter CEMS Demonstration, Dupont, Inc. Experimental Station On-site Incinerator, Wilmington, DE, - Draft Report," October 1997, 187 pp.

22. U.S. EPA, "Total Mercury and Particulate CEMS; Proposed Rule–Notice of Data Availability," Federal Register/Vol. 62, No. 249, December 30, 1997, 30 pp.

23. Schliesser, S. P., M.O. White, et al., "Evaluation of Particulate CEMS at a Hazardous Waste Combustion Facility," in Proceedings of Waste Combustion in Boilers and Industrial Furnaces Conference, Kansas City, April 1998.

24. Schliesser, S. P., M.O. White, et al., "Demonstration of Particulate CEMS at a Hazardous Waste Incinerator," in Proceedings of International Conference on Incineration and Thermal Treatment, Salt Lake City, May 1998.

25. U.S. EPA, Draft Versions: Method 5 I–Low Level Particulate Emissions from Stationary Sources; Performance Specifications 11–Specifications and Test Procedures for Particulate CEMS in Stationary Sources; and Appendix F, Procedure 2-- QA Requirements for Particulate CEMS Used for Compliance Monitoring, November 3, 1998, 64 pp.

26. Bastion, R. E. and R. H. Lambert, "Particulate Matter Continuous Emission Monitor Test Performance in a Moisture-Saturated Flue Gas," in Proceedings of International Conference on Incineration and Thermal Treatment, Orlando, May 1999.

27. Schliesser, S. P., M.O. White, et al., "Designing a Successful Particulate CEMS Correlation Study," Paper 919, Session E3A, at 92nd Annual AWMA Meeting, St. Louis, June 1999.

28. Roberson, R.L., G.C. Clark, and C.E. Dene, "Evaluation of Continuous Particulate Matter (PM) Monitors for Coal-Fired Utility Boilers with Electrostatic Precipitators, at 92nd Annual AWMA Meeting, St. Louis, June 1999.

IV *US References on Other CEMS Technologies*

29. Richards, M. K., L. R. Waterland, and S. B. Ghorishi, "Performance Tests of Mercury Continuous Emissions Monitors at the U.S. EPA Incineration Research Facility, at 89th Annual AWMA Meeting, Nashville, TN, June 1996.

30. Meyer, G.A. and M. Seltzer, "An Argon Plasma Based Continuous Emissions Monitor for Hazardous Air Pollutant Metals," in Proceedings of International Conference on Incineration and Thermal Treatment, Oakland, May 1997.

31. Dunn, J. E., et al., "Evaluation of Candidate Multi-Metals Emissions Monitoring Systems at the DOE Oak Ridge TSCA Incinerator, in Proceedings of International Conference on Incineration and Thermal Treatment, Salt Lake City, May 1998.

32. Lemieux, P.M., et al., Results of the September 1997 DOE/EPA Demonstration of Multimetals Continuous Emission Monitoring Technologies," in Proceedings of International Conference on Incineration and Thermal Treatment, Salt Lake City, May 1998.

33. French, N.B., S.J. Priebe, and W.J. Haas, Jr., "State-of-the-Art Mercury CEMS for Hazardous & Mixed Waste Incinerator Applications," *Environmental Science & Technology*, 1999.

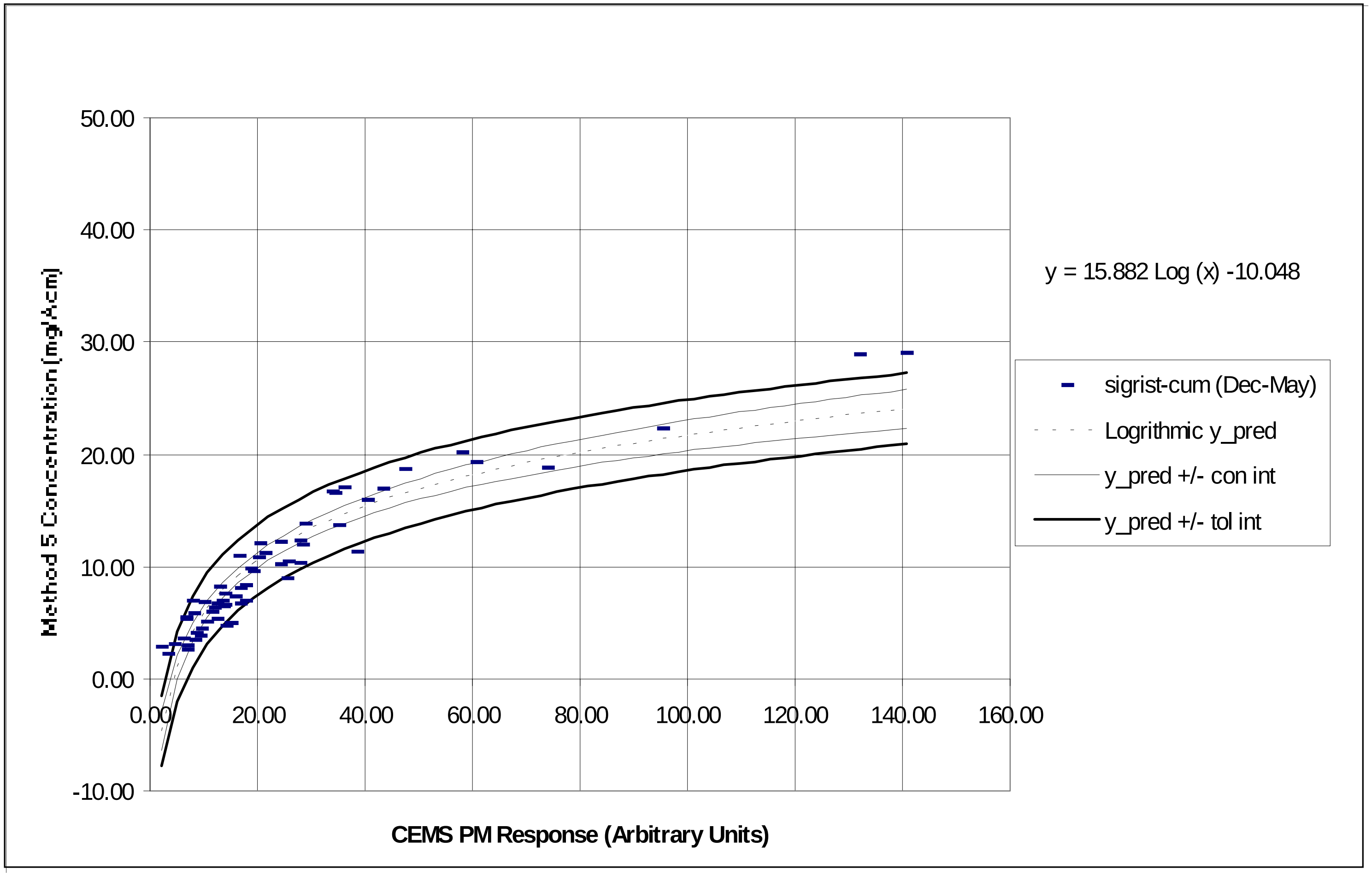


Figure 12-1. Verewa cumulative linear correlation.

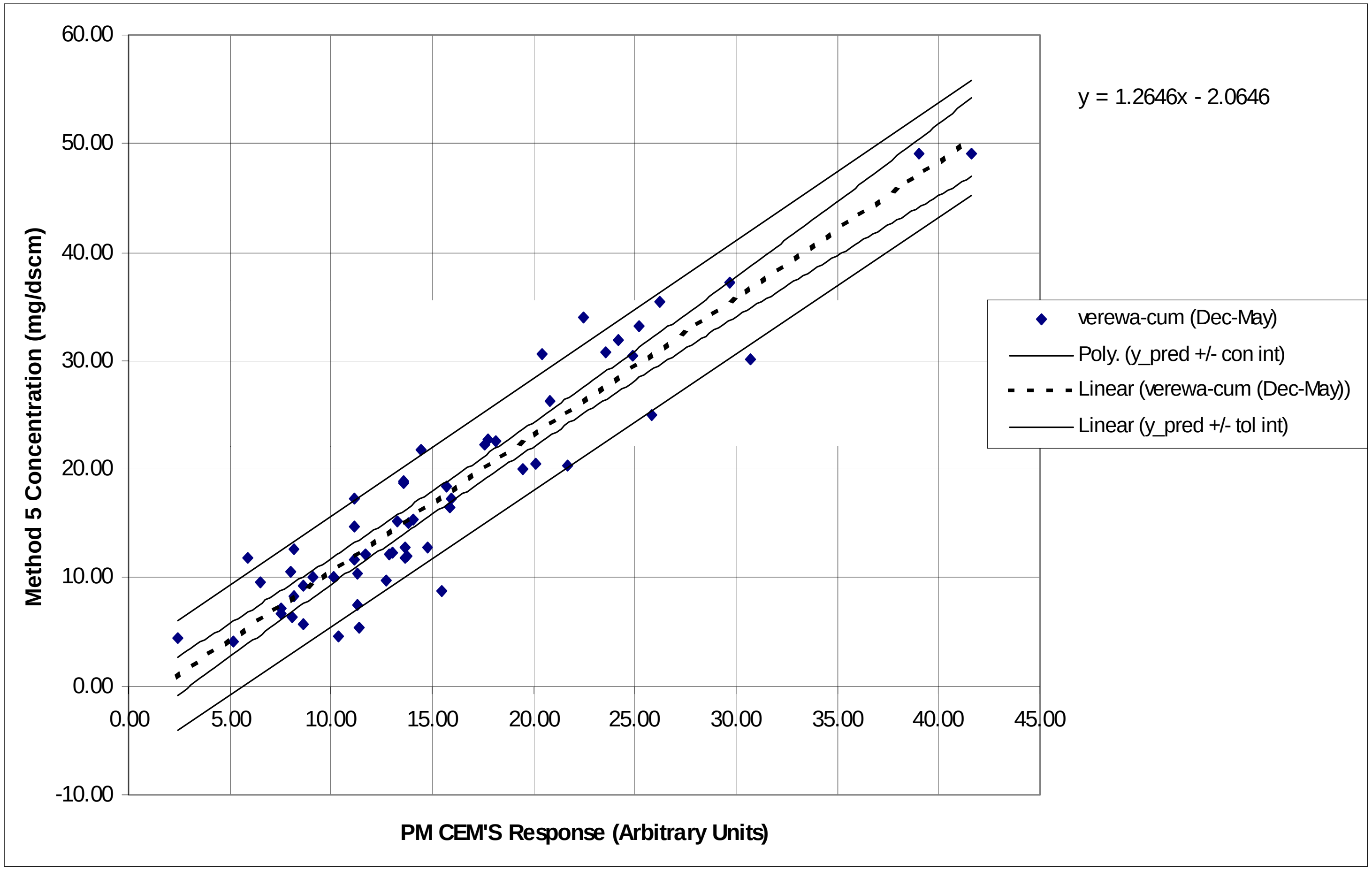


Figure 12-2. Sigrist cumulative logarithmic correlation.

TABLE 12-1. STANDARD DEVIATION OF PM MEASUREMENT METHODS

Proposed PM Standard mg/dscm @ 7% O_2	Best Estimate of the Standard Deviation (mg/dscm)	
	Method 5	Method 5I
34	3.4	1.7
50	5.0	2.2
69	6.9	2.9

TABLE 12-2. COMPARISON OF PM CEMS REQUIREMENTS

Version	Correlation Coefficient	Confidence Interval %	Tolerance Interval %
Original	> 0.90	< 20	< 35
Revised	> 0.90	< 10	< 25

TABLE 12-3. PM CEM CUMULATIVE CORRELATION DATA SUMMARY (DUPONT PM CEM STUDY)

CEMS	Correlation Coefficient	Maximum Confidence Interval % [a]	Maximum Tolerance Interval % [b]
ESA	0.94	5.9	18.5
Verewa	0.94	6.4	22.4
Durag	0.95	6.5	16.8
ESC	0.95	5.7	21.6
Sigrist	0.93	6.6	24.9
Requirement	0.90	10	25

[a] -- These percentages represent the worst-case confidence intervals and correspond to the highest reference method concentration or 69 mg/dscm @ 7% O_2 , whichever is less.

[b] -- These percentages represent the worst-case tolerance intervals and correspond to an emission limit of 34 mg/dscm @ 7% O_2.

TABLE 12-4. RELATIVE ACCURACY OF HG CEMS COMPARED WITH DRAFT METHOD 101B

CEMS	Stack Location	Duct Location	DPS 12 Specification
Verewa HM-1400	31.26 %	66.75 %	20 % of the mean Reference Method value
Perkin Elmer MERCEM	48.95 %	37.30 %	
Seefelder Hg-Mat 2	28.43 %	54.35 %	

TABLE 12-5a. HG CALIBRATION ERROR

CEMS	Level	Results of Hg Calibration Error [a]
Verewa HM-1400	Zero	13.2 % Emission Limit
	Mid	46.6 % Reference Value
	High	22.8 % Reference Value
Perkin Elmer MERCEM	Zero	4.3 % Emission Limit
	Mid	-3.6 % Reference Value
	High	-28.3 % Reference Value
Seefelder Hg-Mat 2	Zero	4.1 % Emission Limit
	Mid	16.3 % Reference Value
	High	-4.3 % Reference Value

[a] -- Draft Performance Specification 12 criteria , ± 15 % of reference value concentration.

TABLE 12-5b. HgCl2 CALIBRATION ERROR

CEMS	Level	Results of HgCl2 Calibration Error [a]
Verewa HM-1400	Zero	No Data
	Mid	No Data
	High	No Data
Perkin Elmer MERCEM	Zero	2.2 % Emission Limit
	Mid	-75.9 % Reference Value
	High	-51.6 % Reference Value
Seefelder Hg-Mat 2	Zero	3.1 % Emission Limit
	Mid	-45.0 % Reference Value
	High	-1.4 % Reference Value

[a] -- Draft Performance Specification 12 criteria , ± 15 % of reference value concentration.

TABLE 12-6. Hg CALIBRATION SOURCE PRECISION FOR CALIBRATION ERROR

Reference Gas	Mean Concentration (ug / dscm)	Average Calibration [a] Precision
Hg	0	0
	24.4	42.8
	50.5	48.2
HgCl2	0	0
	61.8	4.4
	58.2	9.9

[a] -- Draft Performance Specification 12 criteria , ± 5 % of the mean of 3 injections.

TABLE 12-7. GERMAN, ISO, and DRAFT US EPA PERFORMANCE SPECIFICATIONS FOR PARTICULATE CEMS - EQUIPMENT SPECIFICATIONS

Criteria	German	ISO 10155	draft EPA PS 11
Zero drift limit	±2% of full scale	±2% of full scale	±2% of upscale
Upscale drift limit	±2% of full scale	±2% of full scale	±2% of upscale
Automatic cumulative drift (dirt correction)	<6 % of full scale	<6 % of full scale	<6 % of upscale
Simulated zero/upscale drift and test frequency	Specified provisions performed annually	Per manufacturer recommendations	Specified provisions performed quarterly
Response time	Unclear	< reference method sampling time	<2 minutes for continuous units; <15 minutes for batch units
Self-diagnostics with status signal flag	Criteria specified	Unspecified	Criteria specified
Supply voltage, temp., and vibration insensitivity	Criteria specified	General provision included	Under review
Data availability	> 90 %	Unspecified	Under review

TABLE 12-8. GERMAN, ISO, AND DRAFT US EPA PERFORMANCE SPECIFICATIONS FOR PARTICULATE CEMS - CORRELATION TEST SPECIFICATIONS

Criteria	German	ISO 10155	EPA PS 11
Operating condition	Normal range with APCD adjustment	Normal range with APCD adjustment	Normal range with APCD adjustment
Zero test provisions	Included	Included	Included
Minimum sub-ranges	Unclear	3	3
Minimum number of runs	15	9	15
Correlation coefficient	Unspecified	> 0.95	> 0.90
Confidence interval	Unspecified	< 10 %	< 10 %
Tolerance interval	Unspecified	< 25 %	< 25 %
Correlation function	Linear or non-linear	Linear or non-linear	Linear or non-linear

TABLE 12-9. SUMMARY OF GERMAN CORRELATIONS FROM PARTICULATE CEMS SUITABILITY TESTS

Monitor - Type	Facility Type	No. of runs	Range mg/m3	Slope	Correlation Coefficient	Confidence Interval [b]	Tolerance Interval [b]
Sick RM4 - Extinction	Cement Plant	57	10 - 450	a	0.99	a	a
Unspecified - Extinction	Coal Boiler	15	55 - 135	554	0.97	4.4%	11%
Sigrist KTNR - Light Scatter	a	17	0.7 - 2.5	0.36	0.92	7.7%	20%
Verewa F-904 - Beta	Waste Incinerator	15	3.5 - 8	0.98	0.95	9.2%	24%
Durag DR 300-40 - Light Scatter, Unit 1	Lead Smelter	27	0.5 - 1.9	0.16	0.98	3.9%	11%
Unit 2	Lead Smelter	27	0.5 - 1.9	0.15	0.96	5.1%	14%
BHA CPM 1001 - Scintillation, Unit 1	Coal Boiler	15	0 - 150	14	0.99	5.1%	13%
Unit 2	Coal Boiler	15	0 - 150	14	0.99	5.1%	13%
Unit 1	Incinerating Plant	15	0 - 20	1.6	0.99	4.8%	11%
Unit 2	Incinerating Plant	15	0 - 20	1.6	0.99	5.3%	12%
Sigrist CTNR - Light Scatter, Unit 1	Coal Boiler	16	0 - 3	0.27	0.88	9%	21%
Unit 2	Coal Boiler	16	0 - 3	0.27	0.88	9%	21%
Unit 1	Waste Incinerator	13	0.03 - 0.38	0.13	0.95	13%	24%
Unit 2	Waste Incinerator	13	0.03 - 0.38	0.16	0.94	14%	25%
Average Case					0.95	7.3%	16.9%

[a] -- Not reported

[b] -- Confidence and tolerance intervals evaluated at 80% of the maximum reference method value

CHAPTER 13

SPECIAL PROVISIONS

The HWC MACT rule has special provisions for certain systems and for certain waste feeds, specifically for

- Cement kilns with in-line raw mills
- Cement kilns with bypass stacks
- Kilns which cannot meet a standard due to HAPs in the raw materials
- Facilities that feed low levels of metals or chlorine
- Facilities that operate under different modes
- Incinerators with deminimis levels of metal HAPs in their feedstreams

13.1 CEMENT KILNS WITH IN-LINE RAW MILLS

Some cement kilns vent the kiln gas through the mill that grinds the raw materials (the raw mill) to recover energy and help dry the raw materials before charging. When the raw mill is out of service, the kiln continues to operate using stockpiled ground raw materials, and bypassing the raw mill. Emissions of some HAPs can be different, depending on whether or not the raw mill is on-line. Passing through the raw mill provides an additional opportunity to scrub or adsorb metals and chlorine from the kiln gas leading to lower stack emissions of these species when the raw mill is on. Conversely, depending on the temperature, the composition of the raw materials, and on volatility, the hot kiln gas may volatilize some metals and chlorine species out of the raw materials, leading to higher stack emissions of these species when the raw mill is on. In this situation, time-weighted average emissions may be used to determine compliance with Hg, SVM, LVM, and total chlorine standards. Time weighted averaging is not allowed for compliance with:

- the dioxin/furan standard because dioxin/furans are primarily dependent upon the APCD temperature, which cement kiln operators are expected to control, regardless of whether the raw mill is on or off;

- the CO/HC standards because hydrocarbon and carbon monoxide are monitored continually and serve as a continuous indicator of combustion efficiency; and with
- the particulate matter standards because this standard is based on the New Source Performance Standards found in §60.60 Subpart F. EPA interprets these standards to apply regardless if the raw mill is on or off. (Note that this is consistent with the final Nonhazardous Waste Portland Cement Kiln Rule. See 64 FR AT 31898)

Averaging is done according to the following equation:

$$C_{total} = \{(C_{mill\text{-}off}) \times (T_{mill\text{-}off} /(T_{mill\text{-}off} + T_{mill\text{-}on})\} + \{(C_{mill\text{-}on}) \times (T_{mill\text{-}on} /(T_{mill\text{-}off} + T_{mill\text{-}on})\}$$

where:

C_{total} = time weighted average concentration of a regulated constituent considering both raw mill on time and off time.

$C_{mill\text{-}off}$ = average performance test concentration of regulated constituent with the raw mill off-line.

$C_{mill\text{-}on}$ = average performance test concentration of regulated constituent with the raw mill on-line.

$T_{mill\text{-}off}$ = time when kiln gases are not routed through the raw mill

$T_{mill\text{-}on}$ = time when kiln gases are routed through the raw mill.

In the test plan for the comprehensive performance test, facilities must notify the Administrator of their intent to use time-weighted averaging. Historical raw mill operation data must be submitted and used in the test plan to justify allowable time weighting factors (the fraction of time that the mill is expected to be on and off), to estimate the future down-time the raw mill will experience, and to document that estimated emissions and estimated raw mill down-time will not result in an exceedance of the emission standard on an annual basis.

A performance test is performed in two modes: one with the raw mill on and one with the raw mill off. The facility must use the above averaging equation to document in its Notification of Compliance that the emission standard will not be exceeded based on the compliance test emissions and predicted raw mill down-time. Enforceable operating parameter limits are set during a comprehensive performance test for each mode, as described in Sections 3 through 7 and in Section 13.6, which includes the amount of time the raw mill can be offline such that the estimated emissions will be below the applicable standards on an annual basis.

Compliance during continuing operation is determined based on compliance with the operating parameter limits established for each mode. (e.g., 1- hour, and 12-hour rolling average operating limits established in the off-line mode must be complied with whenever the raw mill is off line.) In addition, beginning on the day the owner or operator submits the initial notification of compliance, a once-yearly determination must be made that the facility remains in compliance with the emissions standards. This is done by compiling the historical records of the year to determine the amounts of time the kiln gas was routed and not routed through the raw mill and applying these times to the emissions concentrations measured for each mode of the comprehensive performance test using the above averaging equation to determine if the facility was in compliance for the year. Facilities are advised to continually track their raw mill on/off time throughout the year in order to assure that the once-yearly annual determination will, in fact, demonstrate compliance.

13.2 CEMENT KILNS WITH BYPASS STACKS

Some short cement kilns bypass the preheater and/or precalciner and route a portion of the kiln gas to a separate APCD and stack. This is done to provide an outlet for alkali salts which would otherwise build up because they tend to vaporize in the kiln, condense out in the preheater, and recycle back into the kiln along with the counterflowing raw materials. Some HAPs (e.g., semi-volatile metals) behave much like alkali salts. Because of this, these HAPs tend to be present in much lower concentrations in the gas entering the main APCD and stack than in the gas entering the bypass APCD and stack. Depending on the relative efficiencies of the main and bypass APCDs, emission concentrations in the bypass stack can be significantly different from those in the main stack. In this situation, gas flowrate-weighted average emissions may be used to determine compliance with Hg, SVM, LVM, and total chlorine standards (not D/F or CO/HC standards).

Emission averaging to demonstrate compliance with the hydrocarbon/carbon monoxide standard is not needed at preheater and preheater-precalciner cement kilns with dual stacks since these kilns are only required to monitor hydrocarbon or carbon monoxide in the bypass stack[1] Emission averaging for particulate matter is implicitly required by the format of the standard (0.15 kg/Mg dry feed) which covers mass emissions from both stacks. In addition, emission averaging for dioxin/furans is not allowed because cement kilns with dual stacks are expected to control temperature in both air pollution control systems to comply with the standard.

Averaging is done according to the following equation:

$$C_{tot} = \{C_{main} \text{ x } (Q_{main} /(Q_{main} + Q_{bypass}))\} + \{C_{bypass} \text{ x } (Q_{bypass} / (Q_{main} + Q_{bypass}))\}$$

[1]Note that new kilns at greenfield locations must also comply with a main stack hydrocarbon standard. For these sources, emission averaging for hydrocarbons would not be appropriate because the purpose of the main stack hydrocarbon standard is to control organic hazardous air pollutants that originate from the raw material.

where:

C_{tot} =	gas flowrate-weighted average concentration of the regulated constituent
C_{main} =	average performance test concentration demonstrated in the main stack
C_{bypass} =	average performance test concentration demonstrated in the bypass stack
Q_{main} =	volumetric flowrate of main stack effluent gas
Q_{bypass} =	volumetric flowrate of bypass effluent gas

Facilities planning to comply with emissions standards based on gas flowrate-weighted average emissions must notify the Administrator of this intent, along with a description of the proposed operating limits, in their performance test workplan.

During a performance test, samples must be taken simultaneously from both the main stack and the bypass stack. Operating parameter limits are set from the comprehensive performance test as described in Sections 3 through 7. Sources must document their use of this emission averaging provision in their Notification of Compliance and document the results of the emissions averaging analysis after estimating the flow weighted average emissions with the above equation.

Kilns with bypass stacks must develop operating parameter limits, and incorporate these limits into their Notification of Compliance, that ensure their emission concentrations, as calculated with the above equation, do not exceed the emission standards on a twelve-hour rolling average basis. These operating parameters should limit the ratio of the bypass stack flowrate and combined bypass and main stack flowrate such that the emission standard is complied with on a twelve-hour rolling average basis.

13.3 KILNS WHICH CANNOT MEET A STANDARD DUE TO HAPS IN RAW MATERIALS

Raw materials (and, to a lesser extent, non hazardous waste fuel) for cement kilns and lightweight aggregate kilns can contain SMV, LVM, Hg and/or total chlorine which can be vaporized or entrained into the flue gas. Achievability analysis (discussed in Volume III, Chapter 11) shows that some kilns may have sufficient concentrations of these HAPs in their raw materials to cause them to exceed the emissions standards even though they are using MACT control.

A cement kiln or LWAK may petition the authorized regulatory agency for alternative metal or chlorine standards if it cannot achieve the SVM, LVM, Hg, and/or total chlorine standard (while using MACT control), because of raw material HAP contributions to the emissions. To qualify for the alternative standards, the kiln must use MACT control (defined as the MTECs and technologies listed in Table 13-1), must submit site-specific information that shows raw material hazardous air pollutant contributions to the emissions prevent the kiln from complying with the emission standard even though the kiln is using MACT control, and must submit site-specific information that shows that the source has a system removal efficiency for the HAP which is adequate to meet the MACT standard when feeding the HAP at the MACT feedrate. One way to obtain this information would be to conduct a performance test while using the maximum achievable control technology and demonstrate that the emission standard cannot be met, and to show (assuming the same SRE) that the standard would have been met if metals/chlorine had been fed to the kiln at levels resulting in the MACT MTECs listed in Table 13-1

For example, suppose a hypothetical existing cement kiln with an ESP achieving PM emissions of 0.15 kg/Mg dry feed (MACT technology) conducted a performance test in which the hazardous waste SVM MTEC was 20,000 ug/dscm (which is below the MACT-defining MTEC level of 31,000 ug/dscm), the raw materials MTEC was 20,000 ug/dscm, and the fuel MTEC was 0 ug/dscm (i.e., no fuel, other than hazardous waste, was fired) , resulting in a combined (hazardous waste and raw materials) SVM MTEC of 40,000 ug/dscm. In the performance test, the source measured an SVM emissions concentration of 280 ug/dscm (which is above the MACT standard of 240 ug/dscm). The source calculated its system removal efficiency for SVM according to the formula:

$$SRE = 100\% - (100\% * \text{Emissions Concentration} / \text{Total MTEC})$$

which resulted in an SRE of 99.3%. Using this measured SRE, the facility calculated the projected emissions which would result if the total SVM MTEC were reduced to the 31,000 ug/dscm MACT standard for hazardous waste MTEC (i.e., if SVM were fed at the MACT standard MTEC without any raw materials contributions) according to the formula:

$$\text{Projected Emissions Concentration} = \text{MACT MTEC} * (100\% - SRE)/100\%$$

to be 217 ug/dscm, which is below the MACT standard of 240 ug/dscm. This facility has, therefor, demonstrated that the SVM emission standard cannot be met, and has shown (assuming the same SRE) that the standard would have been met if SVM had been fed to the kiln at levels resulting in the MACT MTEC.

The kiln must also submit data or information (as part of a petition for alternative SVM or LVM standards) documenting that increased chlorine levels associated with the burning of hazardous waste, as compared to non-hazardous waste operations, do not significantly increase metal emissions attributable to raw material. One way to obtain this information would be to conduct two different emission tests at equivalent metals feedrates: the first test to determine metal emission concentrations when the kiln is burning conventional fuel with typical chlorine levels, and the second test to determine metal emissions when chlorine feedrates are equivalent to allowable chlorine feedrates when burning hazardous waste. If metals emissions from the second test are not significantly greater than those from the first, then it would be reasonable to conclude that increased chlorine levels associated with the burning of hazardous waste, as compared to non-hazardous waste operations, do not significantly increase metal emissions attributable to raw material.

The regulatory authority must approve the petition and a Notification of Compliance must be submitted that incorporate the alternative standards before the alternative standards go into effect. This may take some time, so it is wise to apply for the alternative standard (and provide the required information) well in advance (e.g., on a similar schedule to that for submission of comprehensive performance test plans). Alternative standards must be reapplied for (with accompanying information) once every five years on the same schedule as comprehensive performance tests.

13.4 ALTERNATIVE STANDARDS FOR KILNS WITH NONDETECT LEVELS OF MERCURY IN RAW MATERIALS

In some cases, if a lightweight aggregate kiln or cement kiln with nondetect levels of mercury in its raw materials assumed mercury is present in the raw material at the detection limit, the resulting calculated uncontrolled mercury emission concentration could exceed, or be a significant percentage of, the mercury emission standard. This may prevent a kiln from complying with the mercury emission standard pursuant to the provisions of §63.1207(m), even though MACT control was used.

Cement kilns and LWAKS may petition the authorized Regulatory Agency for an alternative mercury standard that only requires compliance with a hazardous waste mercury feedrate limitation, provided it can demonstrate that mercury has historically not been present in the raw material at detectable levels. To comply with the alternative standard, the kiln must implement MACT control (defined as the Hg MTECs as feedrate limits listed in Table 13-1) and must submit site-specific information that shows that mercury has not historically been present in the raw material at detectable levels. The submittal should also provide information that describes the analytical methods (and their associated detection limits) used to measure mercury in the raw materials. Note that we do not define “not historically been present.” We conclude this determination should be made on a site- specific basis. (We do not intend this provision to require a source to demonstrate that Hg has “never been present” in the raw materials at detectable levels.)

The regulatory authority must approve the petition and a Notification of Compliance must be submitted incorporating the alternative standards before the alternative standards go into effect. This may take some time, so it is wise to apply for the alternative standard (and provide the required information) well in advance (e.g., on a similar schedule to that for submission of comprehensive performance test plans). Alternative standards must be reapplied for (with accompanying information) once every five years on the same schedule as comprehensive performance tests.

Sources that are granted this alternative standard will not be required to monitor mercury content of their raw material for compliance purposes. However, since this alternative standard must be approved every five years, it would be wise to develop a raw material mercury sampling and analysis program that can be used in future alternative mercury standard petition requests to demonstrate that mercury has not historically been present in raw material at detectable levels.

13.5 KILNS THAT FEED HAZARDOUS WASTE AT A LOCATION OTHER THAN THE HOT END OF THE KILN

Unlike other kilns, which have the option of complying with CO or HC standards, cement kilns or lightweight aggregate kilns that feed hazardous waste at a location other than the end where products are normally discharged and where fuels are normally fired (e.g., at the mid kiln or cold, upper end of the kiln) must comply with a 20 ppm hydrocarbon standard. This is because of the concern that hazardous waste could be fired into a location where such organic HAPs in the waste may be merely evaporated or thermally cracked to form pyrolysis byproducts rather than be completely combusted. If this occurs, there is the potential that little carbon monoxide will be generated even though significant hydrocarbons are being emitted. Carbon monoxide monitoring would thus not ensure that organic hazardous air pollutant emissions are being properly controlled. This requirement is consistent with existing BIF regulations.

For kilns with a bypass or bypass sampling system, if the waste is fed at a location downstream of the bypass, compliance with the hydrocarbon standard must be demonstrated at the main stack. This requirement is also consistent with existing BIF regulations.

In addition, kilns that feed hazardous waste at a location other than the end where products are normally discharged and where fuels are normally fired must demonstrate compliance with the DRE standard every five years (i.e., in every comprehensive performance test).This is required because of the concern that, due to the unique design and operation of the waste firing system, and due to the decreased residence time and potential for varying levels of temperature and turbulence, the DRE may vary over time, and those variations cannot be identified or limited through operating limits set during a single DRE test.

13.6 FACILITIES THAT FEED LOW LEVELS OF METAL OR CHLORINE

Performance testing requirements for one or more of certain HAPs (mercury, semivolatile metals, low volatile metals, or chlorine) can be waived for sources that feed levels of these HAPs that are sufficiently low so that the emissions standard(s) would not be exceeded even if it is assumed that all HAPs fed to the system (in all feedstreams) were emitted from the stack. This assures compliance with the emissions standard because, unlike organic HAPs, metals and total chlorine are conserved in the combustion process: they can neither be created nor destroyed. All of these species which are fed to the combustor must ultimately be emitted or captured. Thus, it is conservative to assume that everything that is fed to the system is emitted. This is analogous to the "Tier 1" approach used in the BIF rules.

This waiver can be implemented by one of three approaches:

1) A single maximum total feedstream feedrate limit for each HAP (or group of HAPs) and a single minimum stack gas flow rate are established such that the ratio of the HAP feedrate to the stack gas flowrate (i.e., the MTEC), when converted to the appropriate units, does not exceed the emissions standard. Both limits would be complied with continuously on a 12-hour rolling average basis; any exceedance would require the initiation of an automatic waste feed cut-off.

2) Operation would be allowed under different modes, each with its own single maximum total feedstream feedrate limit for each HAP (or group of HAPs) and single minimum stack gas flow rate established and complied with as discussed under approach 1) above. Sources using this approach must clearly identify in the operating record which operating mode is in effect at all times, and must properly adjust their automatic waste feed cutoff levels accordingly.

3) Uncontrolled stack gas emission concentrations can be continuously calculated, assuming all metals or chlorine fed to combustion unit are emitted out the stack. Sources using this approach must record these calculated values and comply with the associated emission standards on a continuous 12-hour rolling average basis. This approach provides greater operational flexibility, but increases recordkeeping since the uncontrolled emission level must be continuously recorded and included in the operating record for compliance purposes.

To document compliance under this waiver, a source must continuously monitor and record the feedrates of the above listed HAPs and continuously monitor and record the gas flowrate. If operating under approach 1 or 2 above, both the flue gas flowrate and the HAP feedrates must be interlocked to trigger an AWFCO if their limits are exceeded. If operating under approach 3 above, the calculated uncontrolled HAP emissions must be interlocked to trigger an AWFCO if their values exceed their emissions standards.

A source which intends to claim this waiver provision, must, in its performance test workplan, document its intent to use this provision and explain which implementation approach is used. Similarly, its Notification of Compliance must specify which implementation method is used, and must incorporate the minimum stack gas flowrate and maximum metal and/or chlorine feedrate as operating parameter limits, or include a statement which specifies that it will comply with emission standard(s) by continuously recording its uncontrolled metal and/or chlorine emission rate.

When a source is operating under this waiver, it is not required to establish or comply with operating parameter limits associated with the metals or chlorine for which the waiver is claimed. For example, a source operating under this waiver for chlorine will not be required to comply with wet scrubber operating parameter limits for chlorine. Note, however, that operating under this waiver for SVM or LVM does not relieve a facility from establishing or complying with operating limits for particulate matter (which is a surrogate for other metal HAPs not included in the SVM and LVM groupings).

A surrogate (e.g., cement kiln production rate) may be used in place of stack gas flow rate. However, the source must provide data in its performance test workplan that clearly and reasonably correlate the surrogate parameter to stack gas flow rate.

When operating under this waiver, metal and chlorine feedstream concentrations (with the exception of mercury in cement kiln or lightweight aggregate kiln raw materials) which are measured below the detection limit must be treated as if they were at the full detection limit. The more conservative full-detection-limit assumption is needed to provide an additional level of assurance that emissions from facilities operating under this waiver still reflect MACT and do not pose a threat to human health and the environment.

Because of the concerns discussed in Section 13.4, it is not appropriate, for purposes of this performance test waiver provision, to require a cement kiln or lightweight aggregate kiln to assume mercury is present at the full detection limit in its raw material when the feedstream analysis determines mercury is not present at detectable levels As a result, kilns are allowed to assume mercury is present at one-half the detection limit in raw materials when demonstrating compliance with the performance test waiver provisions whenever the raw material feedstream analysis determines that mercury is not present at detectable levels.

13.7 OPERATING UNDER DIFFERENT MODES

Under some circumstances, sources may be subject to one set of operating limits in one mode of operation and another set of operating limits in another mode of operation. Different modes of operation are sometimes required. For example, cement kilns with an in-line raw mill must operate in one mode when the raw mill is on and another when it is off. In other situations, although not required, different modes of operation may provide a facility with more flexibility where operating limits must be established on conflicting parameters. For example, an incinerator with a fixed-throat venturi scrubber for particulate control may have difficulty complying with the limit on maximum flue gas flowrate and the limit on minimum pressure drop across the wet scrubber over a wide range of loads and wastes.

Operating parameter limits must be established for each mode of operation. A source must document in the operating record when it changes a mode of operation and must begin complying with the operating parameter limits for the alternative mode of operation. A source must begin calculating rolling averages anew (i.e., without considering recordings from the previous mode) when it begins complying with the operating parameter limits for the new mode of operation. If the facility has previously operated in the new mode, it does not restart its rolling averages; rather, it must incorporate one-minute average values from the last time it operated in that mode so that there is no period of time when the rolling average limits (and associated AWFCOs) are not in effect.

If there is a transition period between one mode and another (i.e., a period of time when the facility is in the process of changing modes), in order to assure that operating limits are achievable in the transition period, it is left to the discretion of the facility to "define" when one mode stops and the next one begins. At that point, the source must begin complying with the operating limits of the new mode. If a facility has conflicting operating limit parameters (e.g., an upper limit on flue gas flow rate and a lower limit on pressure drop across a fixed throat venturi scrubber) and the modes are sufficiently different so that there is no overlap, the facility can use its discretion to "define" when one mode starts and the next one begins separately for each parameter.

For example, a hypothetical cement kiln with an ESP and an in-line raw mill has different operating limits in its two modes of operation for LVM, SVM, Hg, and total chlorine-related parameters. These include:

- Maximum total feedrates of LVM, SVM, Hg, and total chlorine in all feedstreams
- Maximum total pumpable feedrates of LVM and SVM
- Minimum power to the ESP

- Maximum flue gas flowrate
- Maximum inlet temperature to the ESP

The cement kiln conducts a comprehensive performance test under both modes of operation (raw mill on and raw mill off). It uses the procedure discussed in Section 13.1 to demonstrate that it will comply with the LVM, SVM, Hg, and total chlorine standards for the combined modes on a time-averaged basis. Based on the two different modes in the performance test, it establishes limits on the above-listed operating parameters for each mode.

In this particular case, it turns out that the limits on maximum total and pumpable feedrates of LVM are more stringent for the raw-mill-off mode of operation. In preparation for the transition from raw-mill-on to raw-mill-off, the facility reduces its LVM feedrate (by reducing its hazardous waste feedrate, or by switching to a lower-LVM waste) so that the LVM feedrate is below the more stringent LVM limit for the raw-mill-off mode. The source then begins its transition to the raw-mill-off mode of operation. It decides at its discretion exactly when the new mode begins. At that time, it switches its AWFCO settings to the new mode, it designates in its operating record the exact time which the switch-over occurred, and it begins calculating its rolling average compliance parameters for the new mode. For example, for LVM feedrate (a 12-hour rolling average limit) the source stops tallying the 12-hour rolling average for the raw-mill-on mode; rather, the LVM feedrate for the first minute of operation under the raw-mill-off mode is added to the last 11 hours and 59 minutes of operation from the last time the source operated in a raw-mill-off mode.

13.8 ALTERNATIVE PARTICULATE MATTER STANDARDS FOR INCINERATORS

As discussed in Volume III, an alternative particulate matter standard of 0.03 gr/dscf applies to incinerators with deminimis (i.e., nondetect) levels of all CAA metal HAPs (including arsenic, beryllium, chromium, cadmium, lead, antimony, cobalt, manganese, nickel, and selenium) except mercury in their feedstreams. A source may apply for this alternative particulate standard by petitioning the administrator or authorized regulatory agency and including documentation demonstrating eligibility. In order to demonstrate eligibility for this alternative standard, a facility must :

a) conduct feedstream analysis at least annually (more often, if required by the permit writer) to document (that each of its feedstreams does not contain detectable amounts of any of the above-listed metals; and
b) document that its calculated uncontrolled emissions (i.e, the emissions assuming 100% of the metals fed to the incinerator are emitted out the stack), assuming each

metal in each feedstream is present at ½ its detection limit, are below the following limits:

- the sum of the calculated uncontrolled emissions for lead, cadmium, and selenium must be less than the SVM standard of 240 µg/dscm; and
- the sum of the calculated uncontrolled emissions for antimony, cobalt, manganese, nickel, chromium, arsenic, and beryllium are less than the LVM standard of 97 µg/dscm.

The metals listed above have been grouped according to their volatility. This is appropriate because metals of similar volatility have similar behavior with respect to particulate control. Semivolatile metals tend to vaporize in the combustion zone and condense, as the combustion gas cools, into fine particles before entering a particulate control device. Low volatile metals do not vaporize; they either remain in the ash residue or else are entrained as relatively coarse particles. The nonenumerated metal, selenium, is grouped with semivolatile metals cadmium and lead. The nonenumerated metals antimony, cobalt, manganese, and nickel are grouped with low volatile metals chromium, arsenic, and beryllium. Rationale is provided for these groupings in Section 12.1.1 of Volume III.

The one-half detection limit assumption provides a relatively, but not overly, conservative way of assuring that de minimis determinations are not given to sources with very high detection limits. One-half is the arithmetic mean of the two bounds of the range of possible true values for a nondetect measurement (i.e., the full detection limit and zero).

A source may not operate under the alternative particulate matter standard until its petition is approved. It is recommended that the petition be included with the workplan for the comprehensive performance test. The Agency's approval of a workplan containing this petition will be deemed as approval to operate under the alternative particulate emission standard.

TABLE 13-1. MACT FOR HAPS SUBJECT TO FEEDRATE CONTROL IN KILNS

		MACT for Existing Sources		MACT for New Sources	
		MTEC (ug/dscm)	Technology	MTEC (ug/dscm)	Technology
CK	Hg	88	None	7	None
	SVM	31,000	PM Control to 0.15 kg/Mg dry feed	31,000	PM Control to 0.15 kg/Mg dry feed
	LVM	54,000		15,000	
	TCl	720,000	None	450,000	None
LWAK	Hg	24	None	4	None
	SVM	280,000	PM Control to 57 mg/dscm	280,000	PM Control to 57 mg/dscm
	LVM	120,000		46,000	
	TCl	2,000,000	85% Removal	14,000,000	WS with 99.5% Removal

CHAPTER 14

OPERATING AND MAINTENANCE PLAN GUIDELINES

Hazardous waste combustors are required to develop and submit a combustion system operating and maintenance (O&M) plan as part of the comprehensive performance test plan. The plan must cover all aspects of O&M for the various system components, including the combustor, air pollution control system, waste handling and feed systems, etc. The O&M plan will be reviewed and approved by the Agency. The O&M plan will contain site-specific operating and inspection requirements beyond the specifically required operating parameter limits (OPLs) discussed in previous Chapters. Adherence to an O&M plan will help ensure proper operation and performance of the system and continued compliance with the emissions standards of the HWC MACT rule. Coordination between facility operators and permit writers is critical for the development of the O&M plan.

This section discusses some suggested contents for the O&M plans. It is intended to serve only as a guideline for the content of the O&M plans. The O&M plan must cover the combustor and air pollution control devices (APCDs). The details of any O&M plan will be determined on a site-by-site basis by the facilities' unique features and characteristics.

Suggested content of an O&M plan for APCDs including fabric filters (FFs), electrostatic precipitators (ESPs), and wet scrubbers (WSs) are discussed below. More in depth discussions of combustor and APCD O&M procedures can be found in the following sources:

- U.S. EPA, *Wet Scrubber Inspection and Evaluation Manual*, EPA 340/1-83-002, NTIS PB 85-149375, September 1983. Contains detailed information on wet scrubber O&M.

- U.S. EPA, *Operation and Maintenance Manual for ESPs*, EPA/625/1-85/017, September 1985. Contains detailed information on electrostatic precipitator O&M.

- U.S. EPA, *Operation and Maintenance Manual for Fabric Filters*, EPA/625/1-86/020, June 1986. Contains detailed information on fabric filter O&M.

- McKenna, J.D. and Turner, J.H., *Fabric Filter - Baghouses I, Theory Design and Selection*, ETS, Inc., 1989. Contains detailed information on fabric filter O&M.

- U.S. EPA, *Handbook: Operation and Maintenance of Hospital Medical Waste Incinerators*, EPA/625/6-89/024, January 1990. Contains detailed information on fabric filter, wet scrubber, and incinerator O&M information

- Heumann, W.L., *Industrial Air Pollution Control Systems*, McGraw-Hill, 1997. Contains detailed information on fabric filter, wet scrubber, and electrostatic precipitator O&M.

14.1 COMBUSTOR OPERATING AND MAINTENANCE

The O&M procedures for the combustor system (including incinerators, cement kilns, and lightweight aggregate kilns) will contain many elements that are unique to that facility's design. For example, plans for liquid injection incinerators, rotary kilns, fluidized bed, and controlled air will be specific to the site. Suggested guidelines for O&M plans for the combustor will be included in future rule implementation guidance.

14.2 APCD OPERATING AND MAINTENANCE

Suggested procedures for the general operation, inspection, and maintenance of APCD categories including FFs, ESPs, and WSs are outlined.

14.2.1 Fabric Filters

Operation

A maximum and minimum limit on pressure drop is required as an OPL, as discussed in Chapter 4. A maximum limit on flue gas temperature is used as an OPL, as discussed in Chapters 3 and 6. Also, maximum and minimum flue gas temperature operating limits should be set based on fabric tolerance and dew point considerations. Also required, as discussed in Chapter 4, is the use of a "bag leak detection system". Cleaning parameters that should be monitored for common cleaning designs include:

- Shaking -- Frequency, peak acceleration, amplitude, duration
- Reverse-Air -- Frequency, duration, bag tension
- Pulse-Jet -- Frequency, duration

Inspections

FF inspection procedures and intervals may include:

- Daily

  - Stack -- Visible dust
  - Manometer -- Fabric pressure loss, fan static pressure, trends
  - Compressed air system -- Air leakage, valves
  - Collector -- Control panel indicators, listen to system for proper operation
  - Damper valves -- Isolation, bypass, cleaning damper valves
  - Rotating equipment and drives -- Jamming, leakage, and broken parts
  - Dust removal system -- Proper operation, pluggage

- Weekly

  - Filter bags -- Tears, holes, abrasions, proper fastening, bag tension, dust accumulation, creases and folds
  - Cleaning system -- Cleaning sequence and timing, compressed air lines, oilers, filters shaker mechanism
  - Hoppers -- Bridging and plugging, screw conveyor

- Monthly

  - Baghouse integrity -- Visual inspection
  - Shaker mechanism -- Loose bolts
  - Fans -- Corrosion and material buildup, belt drives and chains
  - Monitors -- Accuracy of equipment

- Quarterly

  - Inlet plenum -- Baffle plate, dust deposits
  - Access doors -- Gaskets
  - Shaker mechanisms --
    - Tube type: tube hooks, nylon bushings in shaker bars, clevis assembly
    - Channel type: tube hooks, drill bushings in the tile bars, connecting rods

- Semiannual

  - Motor, fans, etc. -- Lubrication of all electric motors, speed reducers, fans, and similar equipment

- Annual

  - Collector -- Corrosion, all bolts and welds, inspect entire collector, clean, touch up paint

14.2.2 Electrostatic Precipitators

Operation

Power input to each field is a required as an OPL, as discussed in Chapter 4. Flue gas temperature must also be monitored on a continuous basis. Other parameters can also give indications of ESP performance and efficiency, including: particle loading, electrical resistivity of dust, particle size, surface of particles (spheres or leaves), adhesion ability of particulate, cohesion ability of particulate, gas composition, dew point of gases, and cleanliness of discharge electrode and collecting electrode. Consideration should be given for monitoring these where feasible and practical.

Inspections

ESP inspection procedures and intervals may include:

- Daily

  - Ventilating fans
  - Rappers
  - Vibrators
  - Dust removal system
  - Hopper heaters
  - Insulator heaters
  - Transformer-rectifier control power level
  - Opacity
  - Load

- Weekly

  - Hopper level detection operation
  - Transformer-rectifier oil level
  - Transformer-rectifier oil temperature
  - Covering and weather-protection of key interlocks
  - Air leakage around door gaskets and casing penetrations.

- Quarterly

  - Complete current and voltage curves
  - Cleaning of control cabinets and rapper control panel
  - Verify control set points for undervoltage and overcurrent
  - Replacement of filters in ventilation system
  - Rapper wear and alignment

- Annual

  Top of ESP

  - Dielectric testing of oil from transformer-rectifier
  - Verification of key interlock operation
  - Alignment and overall inspection of rappers
  - Vent fan, door, and louver operation
  - Ground switch operation
  - Removal of bus duct inspection covers to inspect and clean insulators
  - Use of ground straps
  - Clean inside and outside of support insulators
  - Clean ventilation supports
  - Tighten loose rapper assemblies
  - Clean penthouse and insulator compartment floor
  - Operation of insulator or penthouse heaters
  - Tightness of high-voltage connection

  Inside of ESP

  - Check collecting surface and discharge electrode alignment of each bus section
  - Remove all dust buildups

- Inspect upper and lower high-voltage support elements
- Rapper placement
- Inspect all collecting surfaces for bows, bends, and distortions
- Check corrosion reviews and documentation (i.e., for casing, collecting surfaces, discharge electrodes)
- Secure and tighten discharge electrodes
- Check perforated plates and tuning vanes for dust buildup and binding
- Condition of anti-sneakage baffles
- Condition of anti-sway insulators
- Placement of internal doors on casing, hopper baffles, perforated plates

Air-load

- Verify control operations
- Verify rapper operation (intensity, lift, frequency)
- Check operating parameters of insulator heaters, hopper heaters, hopper level detectors
- Check current and voltage curve documentation
- Check dust removal system operation

14.2.3 Wet Scrubbers

Operation

OPLs are required as discussed in Chapters 4 and 7 for parameters including: pressure drop, liquid feed rate, liquid-to-gas ratio, liquid feed pH, liquid feed solids content, gas flow rate, and liquid feed pressure.

Inspections

Scrubber inspection procedures and intervals may include:

• Daily

- Scrubber liquid pump -- Proper operation, leakage
- Variable throat activator -- Proper operation and leakage
- Scrubber liquid lines -- Leakage
- Mist eliminator pressure lines -- Leakage
- Reagent feed system -- Leaks

- Fan -- Proper operation, vibration
- Fan bearings -- Abnormal noise
- Fan belt -- Abnormal noise

• Weekly

- Fan -- Lubricate, check oil (level, color, temperature)
- Scrubber liquid pump -- Check oil level and lubricate motor bearings
- Damper air purge system -- Proper operation

• Monthly

- Duct work -- Leakage
- Fan and motor bearings -- Leakage, cracks, loose fittings
- Fan blades and internal housing -- Clean, inspect for material buildup, corrosion and abrasion
- Drain chain drive mechanism -- Chain tension, sprocket wear and alignment, oil level
- Pipes and manifolds -- Plugging and leakage
- Dampers -- Leakage
- Spray bars -- Nozzle wear and plugging
- Pressure gauges -- Check for accuracy
- Main body of scrubber -- Clean, inspect for material buildup, corrosion and abrasion

• Semiannual

- Fan, pump, motor, drag chain bearings and gear reducers -- Clearances and wear, pitting, scoring, leakage, cracks, loose fittings
- Flowmeters -- Check for accuracy
- Damper drive mechanism -- Proper operation and alignment
- Damper seals, bearings, blades, blowers -- Wear and leakage

CHAPTER 15

COMPLIANCE SCHEDULE

The schedule for existing sources (i.e., those constructed or commencing construction or reconstruction before April 19, 1996) for complying with the HWC MACT standards is summarized in Figure 15-1 and in the following bullets:

- The Effective Date of the rule is the date that the rule is published in the Federal Register.

- Within one year after the Effective Date, sources must submit a Notification of Intent to Comply informing EPA and the Public of its intent to comply (or not to comply) with the HWC MACT standards.

- Within two years after the Effective Date
  - Sources must submit a progress report
  - Sources which will not be able to meet the compliance schedule must request an extension to the Compliance Date.
  - Sources which do not intend to comply with the rule must stop burning hazardous waste.

- Two and a half years after the Effective Date (or one year before the comprehensive performance test), sources must submit an initial test plan for their Comprehensive Performance Test.

- Three years (four years if a one-year extension has been granted) after the effective date is the Compliance Date . At this time
  - Sources must be in compliance with the emissions standards and must place Documentation of Compliance in the Operating Record
  - Sources not in compliance with the emissions standards must stop burning hazardous waste

- Within six months after the Compliance Date, sources must conduct their initial Comprehensive Performance Test.

- Within three months after completing the Comprehensive Performance Test, sources must
  - Submit the results of their Comprehensive Performance Test
  - Submit their Notification of Compliance including operating limits set on the basis of the Comprehensive Performance Test.
  - Begin complying with the operating limits specified in the Notification of Compliance and documenting that compliance

  Note that a source may submit a written request to the Administrator for a time extension documenting that it may not be able to meet the 90-day deadline for reasons beyond its control.

15.1 NOTIFICATION OF INTENT TO COMPLY

The Notification of Intent to Comply (NIC) requires sources to prepare an implementation plan that identifies each source's intent to comply with the final rule and to release the plan to the public in a public forum, as well as to formally submit the plan to the Agency certifying the facility's intentions - either to comply or not to comply - and to identify (unenforceable) milestone dates that measure a facility's progress towards achieving compliance with the final emission standards or closure. The NIC process is described in detail in §63.1211 (published in the Federal Register June 19, 1998 as a part of the "Fast Track Rule." It is briefly summarized as follows:

- Within 9 months of the Effective Date (at least thirty days prior to a public meeting) sources must:
  - Make available to the public a draft NIC
  - Publish advance notice of a public meeting to discuss the NIC

- Within 10 months of the Effective Date, sources must conduct a public meeting to discuss the NIC. A summary of this meeting must be included in the final NIC.

- Within one year of the Effective Date, sources must submit a final NIC to the permitting agency.

15.2 PROGRESS REPORT

Within two years of the Effective Date of the HWC MACT standards, sources must either stop burning hazardous waste or submit a progress report to track their actions toward compliance.

As described in detail in §63.1211 (published in the Federal Register June 19, 1998 as a part of the "Fast Track Rule," the progress report must include an update of the schedule of milestones submitted in the NIC and information demonstrating that the source has

- Completed engineering design for any physical modifications needed to comply with the emissions standards

- Submitted construction applications to the applicable regulatory authority

- Entered into a binding contractual agreement to purchase and/or install equipment and modifications necessary to meet the emissions standards.

15.3 DOCUMENTATION OF COMPLIANCE

On their compliance date (3 years after the publication date of the final rule for most sources) sources must begin compliance with the emissions standards and include Documentation of Compliance (DOC) in their operating record. The source must set limits which ensure compliance with the HWC MACT standards (e.g., automatic waste feed cutoff limits, feedrate limits, and operating limits for emission control devices) and include these limits in the DOC along with all information necessary to determine the source's compliance status. These DOC limits must be set based on engineering judgement, which may be based on the results of shakedown tests, manufacturer assertions or specifications, analysis of previous applicable performance tests or knowledge of the performance capabilities of the control equipment.

The DOC limits will remain in effect until submission of a Notification of Compliance. All operating limits identified in the DOC are enforceable limits. However, if these limits are determined, after the initial comprehensive performance test, to not have been adequate to ensure compliance with the MACT standards, the source will not be deemed out of compliance with the MACT emissions standards**,** so as long as it complied with the DOC limits

15.4 MACT PERFORMANCE TESTING SCHEDULES

15.4.1 Comprehensive Performance Testing

The purpose of the comprehensive performance test is to demonstrate compliance and establish operating parameter limits. The comprehensive performance testing schedule is as follows:

- The initial comprehensive performance test must be conducted within 180 days after the Compliance Date.

- Test results must be submitted to the Administrator as part of the notification of compliance (NOC) documenting compliance with the emission standards, continuous monitoring system requirements, and identifying applicable operating parameter limits. The NOC must be postmarked by the 90th day following the completion of performance testing and the continuous monitoring system performance evaluation. In the event of delays beyond the control of the source (for example, if no qualified analytical laboratory is available at the appropriate time), a case-by-case time extension may be requested, subject to the approval of the administrator.

- Subsequent comprehensive performance tests are required approximately every 5 years or less. A subsequent comprehensive performance test must begin no later than 61 months after the beginning of the previous test.

- Results for subsequent comprehensive performance tests must be submitted to the Administrator along with a revised notification of compliance documenting compliance with the emission standards, continuous monitoring system requirements, and revised operating parameter limits. As with the initial NOC, the revised NOC must be postmarked by the 90th day following the completion of performance testing and the continuous monitoring system performance evaluation.

- Site-specific test plans for all comprehensive performance tests, regardless of whether or not they include DRE testing, must be submitted for review and approval by the Administrator at least one year before the comprehensive performance test is scheduled to begin. The regulatory official will has nine months to review the test plan and determine if additional detail is necessary. Note that sources are required comply with the testing schedule even if permit officials have not approved the test plan. The only exception to this requirement is if the test plan proposes to use alternative test methods to those specified in the rule. In that case, the source may not conduct the performance test until the test plan is approved, and the source has 60 days after approval to conduct the test.

- Sixty days prior to the planned test date, a "notification of performance test" must be submitted to the Administrator. Regulatory officials may, but are not required to, review and oversee the testing.

- The Administrator may grant up to a one year time extension for any performance test subsequent to the initial comprehensive performance test. This facilitates consolidation of the MACT performance testing and any other emission testing required for issuance or reissuance of Federal/State permits and allows for delaying tests due to unforseen circumstances. If a delay is granted such that a subsequent comprehensive performance test is performed later than a multiple of five years (plus 30 days) from the initial comprehensive performance test, the anniversary date (and the associated 2-month window) for each comprehensive performance test thereafter is delayed accordingly.

15.4.2 Confirmatory Performance Testing

The purpose of confirmatory performance tests is to measure dioxin/furan emissions under normal conditions midway between comprehensive performance tests to determine if the source is continuing to meet the emission standard. The confirmatory performance testing schedule is as follows:

- A confirmatory test must begin no later than 31 months after the beginning of the previous comprehensive performance test and must be completed within 60 days from the time it began unless the Administrator determines that a time extension is warranted based on documentation in writing of factors beyond the source's control that prevent it from meeting the 60-day deadline.

- As with the comprehensive performance test, confirmatory performance test results must be submitted to the Administrator as part of the notification of compliance (NOC) documenting compliance with the dioxin/furan emission standard. The NOC must be postmarked by the 90th day following the completion of performance testing, unless a time extension is granted.

- Sixty days prior to the planned confirmatory test date, a "notification of performance test" must be submitted to the Administrator. Regulatory officials may, but are not required to, review and oversee the testing.

- As with the comprehensive performance test, the Administrator may grant up to a one year time extension for any confirmatory performance test This allows a source to avoid testing under undesirable weather conditions (e.g., in the winter in Minnesota). Such an extension does not affect the schedule of any subsequent comprehensive performance tests.

15.4.3 Risk Burn/Comprehensive Performance Testing

The MACT comprehensive performance test takes the place of a RCRA trial burn in that it provides a demonstration of compliance with performance standards (including destruction and removal efficiency) and allows operating limits to be set which ensure continuing compliance. However, for some sources, a RCRA trial burn may still be required in order to provide emissions information for a site-specific risk assessment and to allow risk-based operating limits to be set.

Although such a RCRA trial burn is not included or required as part of the HWC MACT standards, it may be imposed as an additional measure for the protection of human health and the environment under the RCRA "omnibus" authority (See §270.32(b)(2)). If a test plan can be developed to satisfy the requirements of both the RCRA risk trial burn and the CAA MACT comprehensive performance test, a source is allowed to combine these tests. Even if it is not possible to meet the requirements of both in the same test, it may save money to conduct the tests back-to-back. The one-year time extension for the comprehensive performance test, discussed above, allows for the coordination of RCRA and MACT testing.

15.4.4 Changes in Design, Operation, and Maintenance

Facilities which change their design, operation, or maintenance practices in a manner which may adversely affect their ability to comply with the emission standards are required to conduct a comprehensive performance test to demonstrate compliance with the affected emission standards and will be required to re-establish operating limits on the affected parameters. In such a case,

- The source must notify the Agency at least 60 days prior to the change, unless the source documents circumstances that dictate that such prior notice is not readily feasible.

- The source must not burn hazardous waste for more than a total of 720 hours after the change and prior to submitting its NOC, and it must burn hazardous waste during this time period only for the purposes of pretesting or comprehensive performance testing.

Note that facilities which change their design, operation, or maintenance practices in a manner which does not adversely affect their ability to comply with the emission standards are still required to document the change in the operating record and must revise as necessary the performance test plan, Documentation of Compliance, Notification of Compliance, and start-up, shutdown, and malfunction plan to reflect these changes.

15.5 NOTIFICATION OF COMPLIANCE

Sources must submit the results of their comprehensive performance test in a Notification of Compliance within three months after the conclusion of the comprehensive performance test The NOC must contain the following information:

- Results of the comprehensive performance test, continuous monitoring system performance evaluation, and any other monitoring procedures or methods that were conducted;
- Test methods used to determine the emission concentrations and hazardous waste feed concentrations, as well as a description of any other monitoring procedures or methods that were conducted;
- Procedures used to identify the appropriate operating limits and feedrate limits;
- Limits for the appropriate operating parameters and hazardous waste feedrates that are necessary to determine continued compliance with the emission standards;
- Other reporting requirements that are applicable to the source, (i.e., the frequency of future performance or confirmatory tests, excess violations report requirements, continuous monitoring system performance evaluations, automatic waste feed cutoff system checks, continuous emissions monitoring systems relative accuracy test audit requirements and performance checks, operator training requirements, etc.);
- A description of the air pollution control equipment and the associated hazardous air pollutant that each device is designed to control, as well as a description of the monitoring technique and methods that ensure control of the associated hazardous air pollutant; and
- A statement from the company's responsible official that the facility is in compliance with the relevant standards and requirements of the HWC MACT standards.

Year 0	Year 1	Year 1.5	Year 2	Year 2.5	Year 3	Year 3.25	Year 3.5	Year 3.75	Year 4.5 [4]
				Option 1A	*Option 2*			*Option 3*	*Option 1B*
HWC MACT rule published	NIC due to regulatory agency		Progress report due to regulatory agency	Performance test plans due	DOC in operating record [3]	Notification of test plan approval or intent to deny	Performance tests completed	NOC, including test results, due to regulatory agency	
EFFECTIVE DATE					COMPLIANCE DATE				
	Title V permit applications due to permitting authority [1]	Reopenings complete for sources with 3 or more years left in permit term		Title V permit decisions made [2]					Revise title V permit to include NOC

Notes:

1/ Sources newly subject to title V as a result of the hazardous waste combustor (HWC) MACT rule have 12 months to submit applications. Sources that have title V permits with a remaining permit term of 3 or more years when the HWC MACT rule is promulgated must reopen the permit to address HWC MACT. Such a reopening must be completed within 18 months of rule promulgation. Sources with title V permits with less than 3 years remaining in the permit term do not have to reopen; they can wait until renewal to address HWC MACT. However, in the interim, sources must meet the HWC MACT requirements.

2/ By statute, permitting authorities have 18 months to act on title V applications, if they are submitted after the first full year of a title V permit program. This means that decisions on title V applications or reopening requests submitted at Year 1 would be made by Year 2.5 -- still a year before sources conduct the performance test (which (1) provides operating parameters for the unit, (2) demonstrates compliance with the standards, and (3) provides data for the notification of compliance (NOC)). However, permitting authorities are behind schedule in issuing title V permits; thus, we cannot assume that permits will have been issued by this point. We also cannot assume they will not be issued, because the permitting authorities may "catch up" with their schedule.

3/ Although the source is subject to enforceable *requirements* from the time of MACT promulgation (e.g., requirements for the Notice of Intent to Comply (NIC), the progress report, performance tests, and so on), this is the first point at which the source is subject to enforceable *operating conditions* (those contained in the DOC maintained in the source's operating record); however, these conditions have not yet been demonstrated to actually achieve the standards.

4/ It could take up to nine months to incorporate significant permit revisions (see 40 CFR §§70.7(e)(4)(ii) and 71.7(e)(3)(ii)).

Figure 15-1. Hazardous Waste Combustor MACT implementation time line: options for timing of permit transition.

CHAPTER 16

TEST METHODS

This section discusses test methods used for showing compliance.

16.1 MANUAL STACK GAS SAMPLING TEST METHODS

Stack gas sampling with manual test methods is required for PM, metals (Hg, SVM, and LVM), chlorine, and PCDD/PCDF. These are discussed. Note that where applicable, equivalent SW-846 Methods may be used as well.

16.1.1 Metals

EPA Method 29, in 40 CFR Part 60, Appendix A, is required for compliance with the MACT standards for mercury, semivolatile metals, and low volatile metals.

16.1.2 Total Chlorine (Hydrochloric Acid and Chlorine Gas)

EPA Method 26A, in 40 CFR Part 60, Appendix A, is required for compliance with the total chlorine MACT standard (hydrochloric acid and chlorine gas).

It has been suggested that Method 26A is biased high at cement kilns because it collects other chloride salts, in particular ammonium chloride, in addition to the hydrochloric acid and chlorine gas emissions it was designed to report. However, the MACT chlorine standard was based on data from the SW-846 equivalent to Method 26A (Method 0050). Therefore, the standard inherently accounts for the ammonium chloride collection bias. Also, other work has shown through alternate methods that HCl is present in cement kiln stack gases, and that the bias may not be significant.

If there is concern about the potential bias, it may be requested to use Fourier Transform Infrared or Gas Filter Correlation Infrared techniques if, following the provisions found in 40 CFR

63.7, those methods are shown to pass a Part 63, Appendix A, Method 301 validation at the source. Note that after further review and consideration of the GFCIR Method (322), EPA is not promulgating its use in the Portland Cement Kiln MACT rulemaking due to problems encountered with the method during emissions testing at lime manufacturing plants.

16.1.3 Particulate Matter

Compliance with the particulate matter MACT standard requires the use of either EPA Method 5, or newly developed EPA Method 5i, in 40 CFR Part 60, Appendix A.

The selection of the method depends on the expected PM emissions level during the performance test. In cases of low levels of particulate matter (i.e., for total train catches of less than 50 mg), it is recommended that Method 5i be used. For higher emissions, Method 5 may be used. Note that this total train catch is not intended to be a data acceptance criteria. Thus, total train catches exceeding 50 mg do not invalidate the method. In practice this will likely mean that all incinerators and most lightweight aggregate kilns will use Method 5i for compliance, while some lightweight aggregate kilns and some cement kilns will use Method 5. Note that Method 5i has been shown to have better precision than Method 5.

16.1.4 PCDD/PCDF

Compliance with the PCDD/PCDF MACT standard requires the use of EPA SW-846 Method 0023A, in "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods," EPA SW-846.

Method Sampling Time and Volume Requirements

To assure testing consistency from source to source, and that results are representative (have adequate accuracy and sensitivity), it is required to run Method 0023A for a minimum of three hours for each run, and to collect a flue gas sample volume of at least 2.5 dscm. This requirement is appropriate for all sources, regardless of size or type. Note that this requirement is consistent with the requirements included in the final Portland Cement Kiln MACT rule (see 64 FR 31898).

Handling of Non-Detects

As per Method 23 and the proposed rule, non-detected congeners may be assumed to not be present in the emissions when calculating TEQ values for compliance purposes (i.e., non-detects may be treated as zero). (Note that Method 0023A does not make a clear statement on how measurement non-detects should be handled, whereas Method 23 specifically instructs that, for compliance purposes, non-detects should be taken as zero.)

Specification of required minimum detection limits for each congener analysis was considered to assure that sources achieve reasonable detection limits, and prevent abuse and understatement of potential PCDD/PCDF emissions. However, for a variety of reasons, minimum congener detection limits are not specified.

Instead, PCDD/PCDF congener detection limits that are to be achieved are to be included in the Agency-reviewed and approved performance test workplan. Facilities should submit information that describes the target detection limits for all congeners, and calculate a PCDD/PCDF TEQ concentration assuming all congeners are present at the detection limit. If this value is close to the emission standard (for example, within one-half), both the source and the regulatory official should determine if it is appropriate to either sample for longer time periods or investigate whether it is possible to achieve lower detection limits by using different analytical procedures that are approved by the Agency.

This treatment of non-detects and sample time and volume requirements are based on the following considerations.

The basic analytical procedures for EPA Method 23 and EPA SW-846 0023A were first developed in the late 1980s. Target detection limits (TDL) which were originally specified (based on those that a qualified laboratory should be able to achieve) are shown in Table 16-1. Data from this table have been directly incorporated into Method 0023A. Note that for Method 0023A, the mass of any specific congener contained in the sample is the sum of the mass detected in front half plus that found in the back half.

There are many implications to the detection limits achieved by the analytical laboratory. Consider the case where the laboratory reports that the none of the PCDD or PCDF congeners were present at sufficient concentration to quantify, and that the analytical detection limits for the measurements were equal to the TDLs listed in Table 16-1. Assuming the source was operating with an average excess air level consistent with 7% O_2 in the stack, and that the sampling contractor collected sample gas for approximately 3 hours at a sampling rate of 0.5 cfm, Table 16-2 shows the upper limit concentration of PCDD/PCDF in the stack at about 0.4 ng TEQ/dscm (based on the assumption that each congener is present at the analytical target detection limit of Method 0023A). This is essentially equal to the standard option of 0.4 ng TEQ/dscm, and about twice that of the option of 0.2 ng TEQ/dscm. If the combustor was operating at higher excess air level (higher oxygen level), the measurement detection limit would probably exceed the 0.4 ng TEQ/dscm option. This outcome is clearly inappropriate from a compliance perspective. The measurement detection limit must be well below the actual emission standard. Thus, it is not appropriate to treat non-detect data at the full detection limit. Note that as discussed below, this is not to imply that the method sensitivity for showing compliance with the standard is inadequate. In fact, actual detection limits that are achieved in current practice are much below the original TDLs.

There are two primary approaches for reducing detection limits. The first is to increase the quantity of analyte collected during the sampling process. This implies increasing the sample extraction time and/or the sample extraction rate. The second avenue for improving the measurement detection limit is for the laboratory to achieve results superior to that indicated by the TDLs listed in Table 16-1.

It is certainly possible for the sampling team to increase the time for sample extraction beyond the typical 3-hour period -- something routinely done in many test programs. The sample extraction rate can be increased above the 0.5 cfm rate assumed in the calculations of Table 16-2. Note however, that proper operation of the sampling train requires that the sampling rate be maintained within certain bounds and that sample rates much in excess of 0.75 cfm are not recommended. There are other practical limits which should also be considered. The filter module is continually collecting solid material. The longer the sampling duration, the more solid material collected and the greater the pressure drop across the filter. For a dirty stack, long sampling periods could be a problem. However, for a facility meeting the MACT PM standards, extended sampling times should not be a major concern.

The most likely avenue for significant reduction in measurement detection limit is through improved laboratory operation. Recall that the TDLs listed in Table 16-1 were developed more than a decade ago and even then contained a safety factor relative to typical operations. In the subsequent years there has been marked improvement in both laboratory equipment and laboratory technique. Informal telephone interviews were held with three major analytical laboratories to assess the dioxin and furan detection limits being routinely achieved. The laboratories contacted included Triangle Laboratories in RTP. NC, Paradigm Laboratories in Wilmington, NC, and Phillips Analytical in Canada. Each of these companies routinely track the detection limits being achieved and perform statistical assessments of their performance. It is fair to say that there is significant variation between the laboratories contacted but all of the labs are routinely achieving analytical detection limits significantly lower than those listed in Table 16-1. A reasonable upper limit for "typical" operation is to take the mean plus two standard deviations. Using that approach all three laboratories are achieving analytical detection limits that are at least a factor of 2 lower than indicated in Table 16-1 and typically the lab performance is a factor of 5 or 6 below the listed TDLs.

Based on the above analysis it is concluded that EPA SW-846 Method 0023A is capable of routinely achieving measurement detection limits well below the MACT standard for all source types. The TDLs listed in the EPA SW-846 Method 0023A should also be taken as marginal analytical laboratory performance. Typical lab operation achieves analytical detection limits that are at least a factor of 2 lower. That lab performance combined with three hours of sampling at 0.5 cfm should produce a measurement detection limit of no more than 0.2 ng TEQ/dscm. That is a factor of two below the upper PCDD/PCDF standard option. If the facility intends to comply with the 0.2 ng TEQ/dscm standard option, either improved analytical detection limits or increased sampling time is recommended.

Potential Formation in Sampling Train

Concern has been expressed about potential bias in the EPA SW-846 Method 0023 sampling train due to catalytic PCDD/PCDF formation in the sampling train probe, line, and filter, due to favorable conditions (temperature and entrained PM).

First, the method does not preclude use of a water cooled or air cooled probe and nozzle; however it is not standard practice to use such cooling. Second, there is nothing in the method that requires gas temperatures to be measured. The hot box environment surrounding the PM filter is required to be controlled to 250°F. However, the temperature of the gas carrying glassware or the filter itself may be well above the hot box temperature for hot stack gases.

As a practical matter though, with respect to PCDD/PCDF formation when the suspended particles travel the length of the probe, there is likely not much difference between the PCDD/PCDF concentration at the stack exit and the concentration of the sample exiting the filter. For typical sampling train operation near isokinetic conditions, the velocity of the gas in the probe will be about one-quarter the stack velocity. A typical probe length is as close to the stack diameter as possible. Thus, a reasonable estimate is that the residence time of the gas in the sampling probe under potentially hot conditions is approximately the same as the time it takes the flue gas to travel four stack diameters. Four stack diameters is on the same order as the location of typical stack sampling platforms from the top of the stack.

Formation in the PM filter is still a potential concern. However, significant catalytic PCDD/PCDF formation is not expected to occur in the sampling train filter (in comparison to that which would occur in the upstream APCD and combustor system) because:

- The actual filter temperature must be lower than that of the stack gas or any of the APCD equipment. The actual temperature will depend on the sample probe length and heat transfer characteristics and hot box operating conditions (temperature, design, etc.)

- The particulate loading in the stack gas pulled through the sampling train is very low, and certainly much lower than that in the flue gas prior to any PM APCD, thus reducing potential catalytic formation. In a similar manner, the amount of PM hold up in the filter over the sampling period is very small in comparison to PM hold up in the primary system APCD, again reducing potential PCDD/PCDF catalytic formation.

- Flue gas residence time across the sampling train filter is much smaller than the residence time in a typical FF or ESP. Thus, the opportunity for catalytic formation through gas phase constituent and PM is reduced in the sampling train.

Note that almost immediately after the gases exit the hot box they are rapidly cooled in a condenser prior to the XAD trap.

Other Notes

Note additionally:

- The main difference between Method 0023A and Method 23 is that with Method 23, the "front" and "back" halves are extracted and combined prior to analysis. There are clear advantages to combining the fractions for a single analysis, however this procedure suffers from the fact that poor recovery of materials collected in the filter is often not discovered. Method 0023A gets around that issue by adding internal standards to both the front and back halves, separately extracting the halves and separately analyzing the halves.

- PCDD/PCDF results may not be "blank" corrected, as per method guidance.

- EPA has developed analytical standards for certain mono- through tri-chloro PCDD and PCDF congeners. It is encouraged to test for these congeners in addition to the congeners that comprise the TEQ determination. The source is requested that results for these additional congeners be included in the Notification of Compliance. It is planned to use this data to determine if any of these compounds can act as surrogate(s) for the PCDD/PCDF congeners which comprise the total and TEQ. This is attractive because they may be more amenable to measurement with a CEMS. A complete list of these congeners will be included in the implementation document for this rule and updated periodically through guidance.

16.1.5 Combined Methods

Any applicable and comparable SW-846 test methods may also be requested to demonstrate compliance. For example, SW-846 Method 0050 for particulate matter and total chlorine (hydrochloric acid and chlorine gas) in place of EPA Method 5 and Method 26A.

16.2 SOLID/LIQUID SAMPLING METHODS

EPA SW-846 test methods are recommended for use for characterization of liquid and solid feed streams for ash, chlorine, and metals, as required under the HWC MACT rule. However, as part of a move toward performance based measurement methods, other methods may be requested in an Agency-reviewed and approved comprehensive performance test plan and feedstream analysis plan. These methods must be shown to be unbiased, precise, and representative. This should involve quality assurance and quality control method checks including recovery of spiked (or surrogate) analytes, and reproducible results.

TABLE 16-1. PCDD/PCDF ANALYTICAL TARGET DETECTION LIMITS (TDLs)

Analyte	Target Detection Limit (pg/sample train)
TCDD/TCDF	50
PeCDD/PeCDF	250
HxCDD/HxCDF	250
HpCDD/HpCDF	250
OCDD/OCDF	500

TABLE 16-2. DETECTION LIMIT CALCULATION FOR
EPA SW-846 METHOD 0023A EXPRESSED AS I-TEQ

PCDD/PCDF in Stack Gas	I-TEF Factor	SW-846 Method 0023		
		Front Half (ng)	Back Half (ng)	Total (I-TEQ ng)
2,3,7,8 TCDD	1.0	0.05	0.05	0.1
1,2,3,7,8 PeCDD	0.5	0.25	0.25	0.25
1,2,3,4,7,8 HxCDD	0.1	0.25	0.25	0.05
1,2,3,6,7,8 HxCDD	0.1	0.25	0.25	0.05
1,2,3,7,8,9 HxCDD	0.1	0.25	0.25	0.05
1,2,3,4,6,7,8 HpCDD	0.01	0.25	0.25	0.005
OCDD	0.001	0.5	0.5	0.001
2,3,7,8 TCDF	0.1	0.05	0.05	0.01
1,2,3,7,8 PeCDF	0.05	0.25	0.25	0.025
2,3,4,7,8 PeCDF	0.5	0.25	0.25	0.25
1,2,3,4,7,8 HxCDF	0.1	0.25	0.25	0.05
1,2,3,6,7,8 HxCDF	0.1	0.25	0.25	0.05
2,3,4,6,7,8 HxCDF	0.1	0.25	0.25	0.05
1,2,3,7,8,9 HxCDF	0.1	0.25	0.25	0.05
1,2,3,4,6,7,8 HpCDF	0.01	0.25	0.25	0.005
1,2,3,4,7,8,9 HpCDF	0.01	0.25	0.25	0.005
OCDF	0.001	0.5	0.5	0.001
Total Sum (ng)			5.1	1.002
Gas sample rate (cfm)				0.5
Sampling time (hours)				3.0
Gas Volume (m^3)				2.55
Oxygen (%)				7
PCDD/PCDF (ng/dscm I-TEQ @ 7% O_2)				0.39

CHAPTER 17

REVISIONS TO THE COMPARABLE FUEL SPECIFICATION

Revision of the specification levels for the Comparable Fuels Final Rule is required after subsequent review of the released Specifications. Several types of technical corrections were identified. Each of the revisions/corrections to the specifications listed in the Final Rule are addressed in this chapter.

The attached Table 17-1 shows the revised and corrected Comparable Fuel Specification levels for all constituents. Note that the Comparable Fuel Specifications are based on the highest level observed in the benchmark fuels.

The attached Appendix B provides all of the laboratory results for the fuel samples. Appendix B contains all of the data used for determining the individual Comparable Fuel Specifications. Note that there were also some data that were not included in the Final Rule Technical Support Document (TSD). The omitted data has been included in the attached Appendix B.

Also, note that the units of measure referenced in the header of Appendix B of the Final Rule TSD were mistakenly labeled as mg/L instead of mg/kg. The units in the laboratory data were verified as mg/kg. The header has been corrected in the tables in Appendix B of this document.

17.1 VOCs IN GASOLINE

VOC data from the gasoline samples was not used for setting comparable fuel specifications. This was due to the elevated laboratory VOC detection limits which resulted from the preparation of the gasoline samples. The gasoline samples required much greater dilution than the other types of fuel samples because the volatile fraction represents the majority of the constituents of gasoline. Specifically, sample dilution of the gasoline was required to quantify one of the compounds (toluene) within the GC/MS calibration range. The undetected analytes were not expected to be present in any of the gasoline samples. Therefore these elevated detection limits were not considered for the determination of the specification levels in the Final Rule. Note that the semi-volatile fraction represents the majority of the constituents in the three fuel oil types analyzed.

Note that this was clearly document in the Final Rule Technical Support Document (May 1998) on page 3-5, Section 3.4.1, the second paragraph:

> "When calculating the quantitation limit for volatile organic compounds (VOCs) in gasoline, in the analytical methods, there is matrix interferences that cause the calculated quantitation limits to be unreliable. Therefore, for the VOCs that were not detected in any of the gasoline samples, the estimated 90^{th} percentile is not presented in Appendix B, Table 1. For these chemicals, the 90^{th} percentile estimate from the composite of the Nos. 2, 4, and 6 fuel oils is presented in Appendix C, Table 1 as a surrogate for the 90^{th} percentile for gasoline."

17.2 METALS

The detection limit (DL) for each metal was calculated by multiplying the dilution factor (DF) used for the sample preparation by the respective laboratory detection limit. The laboratory detection limits for the methods used by the laboratory are tabulated below.

Laboratory Detection Limits for Metals

Analyte	Detection Limit, mg/kg	Analyte	Detection Limit, mg/kg
Antimony	0.50	Lead	0.50
Arsenic	0.01	Manganese	0.05
Barium	1.0	Mercury	0.10
Beryllium	0.05	Nickel	0.20
Cadmium	0.05	Selenium	0.01
Chromium	0.10	Silver	0.10
Cobalt	0.20	Thallium	1.0

During the review of the laboratory data, it was apparent that the Quantitation Limit (QL) for Selenium and Silver for No. 2 Fuel Oil sample #5 and No. 6 Fuel Oil sample #5 were transposed. This conclusion was based on the DF of the sample preparation and the QL listed in Appendix B. The raw laboratory data was checked to verify the error. Appendix B contains the corrected data.

Specific changes to the metals Comparable Fuel Specifications include, as shown in Table 17-1:

- The value for Antimony in the TSD and Final Rule cited the value of 7.9 "Concentration Limit (mg/kg at 10,000 Btu/lb)". The highest detected concentration of Antimony normalized for the associated heating value of the fuel was corrected to 8.7 mg/kg at 10,000 Btu/lb. The highest reported detection limit in the benchmark fuel where Antimony was not detected was 11.5 mg/kg (for No. 4 Fuel Oil sample #1). Therefore, the concentration for Antimony has been changed to 12 mg/kg at 10,000 Btu/lb (using two significant figures).

- The value for Mercury in the TSD and Final Rule was entered as 0.24 mg/kg at 10,000 Btu/lb. This value represented an estimate of the 99th percentile value. Mercury was not detected in any of the fuel samples used to determine the benchmark fuel concentration level. The highest observed detection limit for Mercury was 0.25 mg/kg (from the No. 6 Fuel Oil sample #6). The revised concentration for Mercury is 0.25 mg/kg at 10,000 Btu/lb.

- The value for Selenium in the TSD and Final Rule was derived from the laboratory analysis of No. 6 Fuel Oil sample #1. Selenium was quantified at 0.28 mg/kg. The associated heating value for this fuel sample was 18,400 Btu/lb. The result was normalized to 0.15 mg/kg at 10,000 Btu/lb. The highest observed detection limit where Selenium was not detected was 0.23 mg/kg (from the No.4 Fuel Oil sample #1). The concentration for Selenium has been edited to 0.23 mg/kg at 10,000 Btu/lb.

The specification levels for the remaining metals: Arsenic, Barium, Beryllium, Cadmium, Chromium, Cobalt, Lead, Manganese, Nickel, Silver, and Thallium, have not been changed from the final rule.

17.3 HYDROCARBONS

The following criteria is used to set hydrocarbon comparable fuel specifications. If a hydrocarbon was detected in one of the benchmark fuels, the concentration was normalized to 10,000 Btu/lb based on the associated heating value of the sample. If the normalized concentration resulted in a *higher* value than the highest observed laboratory detection limit, then the normalized value would be entered into the specification. If the normalized concentration resulted in a *lower* value than the highest observed laboratory detection limit, then the highest observed detection limit would be entered into the specification. That is to say:

- If a detected concentration at 10,000 Btu/lb was greater than the highest observed laboratory detection limit, then concentration at 10,000 Btu/lb is used.

- If a detected concentration at 10,000 Btu/lb was less than the highest observed laboratory detection limit, then highest observed laboratory detection limit is used.

Specific changes to the hydrocarbon Comparable Fuel Specifications include, as shown in Table 17-1:

- The specification level for Benzo[a]anthracene was listed in the TSD and Final Rule as 1100 mg/kg at 10,000 Btu/lb. The specification concentration limit was derived from the detection of Benzo(a)anthracene in No. 6 Fuel Oil sample #4. However, the normalized concentration is less than the highest observed laboratory detection limit of 2400 mg/kg. The revised value has therefore been entered as the highest observed laboratory detection limit of 2400 mg/kg.

- The specification levels for Benzo[b]fluoranthene and for Indeno(1,2,3-cd)pyrene were listed in the TSD and Final Rule as 960 mg/kg at 10,000 Btu/lb. These values represented the estimated 99th percentile values for the composite of all four fuel types. The revised values have been entered as the highest observed laboratory detection limit of 2400 mg/kg.

- The specification levels for Benzo[k]fluoranthene; 7,12-Dimethylbenz[a]anthracene; Fluoranthene; and 3-Methylchloanthrene were listed in the TSD and Final Rule as 1900 mg/kg at 10,000 Btu/lb. These values represented estimated 99th percentile values for the composite of all four fuel types. The revised values have been entered as the highest observed laboratory detection limit of 2400 mg/kg for each compound.

- The specification level for Benzo[a]pyrene was listed in the TSD and Final Rule as 960 mg/kg at 10,000 Btu/lb. Benzo(a)pyrene was detected in No.6 Fuel Oil sample #5 at 960 mg/kg. However, the normalized concentration is less than the highest observed laboratory detection limit of 2400 mg/kg. The revised value has been entered as the highest observed laboratory detection limit of 2400 mg/kg.

- The specification level for Chrysene was listed in the TSD and Final Rule as 1400 mg/kg at 10,000 Btu/lb. Chrysene was detected in No. 6 Fuel Oil sample #4 at 2700 mg/mg. However, the normalized concentration is less than the highest observed laboratory detection limit of 2400 mg/kg. The revised value has been entered as the highest observed laboratory detection limit of 2400 mg/kg.

- The specification level for Dibenzo[a,h]anthracene was listed in the TSD and Final Rule as 960 mg/kg at 10,000 Btu/lb. Dibenzo[a,h]anthracene was detected in No. 6 Fuel Oil sample #5 at 250 mg/kg. However, the normalized concentration is less than the highest observed laboratory detection limit of 2400 mg/kg. The revised value has been entered as the highest observed laboratory detection limit of 2400 mg/kg.

The specification levels for Naphthalene, Benzene, and Toluene have not been changed from the values cited in the Final Rule. These compounds were detected at a normalized concentration greater than the highest observed laboratory detection limit.

17.4 OXYGENATES

Oxygenate comparable fuel specifications are set in a similar manner to that discussed above for hydrocarbons. No oxygenates were detected in any of the fuel oil samples. Therefore, the highest observed laboratory detection limit is used in the comparable fuel specification table (as shown in Table 17-1). Gasoline VOC oxygenates, as discussed above, were not used due to high detection limits that were achieved.

Changes to the oxygenate Comparable Fuel Specifications include:

- The specification levels for Acetophenone; bis(2-Ethylhexyl)phthalate; Butyl benzyl phthalate; Di-n-butyl phthalate; Diethyl phthalate; 2,4-Dimethylphenol; Dimethyl phthalate; Isosafrole; 1,4-Naphthoquinone; Phenol; and Safrole were listed in the TSD and Final Rule as 1900 mg/kg at 10,000 Btu/lb. These values represented the estimated 99th percentile values for the composite of all four fuel types. The revised values have been entered as the highest observed laboratory detection limit of 2400 mg/kg for each compound.

- The specification level for Di-n-octyl phthalate was listed in the TSD and Final Rule as 960 mg/kg at 10,000 Btu/lb. This value represented the estimated 99th percentile value for the composite of all four fuel types. The revised value has been entered as the highest observed laboratory detection limit of 2400 mg/kg.

- The specification levels for Acrolein; Ethyl methacrylate; Isobutyl alcohol; Methyl ethyl ketone; and Methyl methacrylate were listed in the TSD and Final Rule as 37 mg/kg at 10,000 Btu/lb. These values represented the estimated 99th percentile values for the composite of the No. 2, No. 4 and No. 6 fuel oil samples. The revised values have been entered as the highest observed laboratory detection limit of 39 mg/kg for each compound.

- The specification level for each of the isomers of Cresol (ortho, meta, and para) were listed in the TSD and Final Rule as 220 mg/kg at 10,000 Btu/lb. The revised value has been entered as the highest observed laboratory detection limit of 2400 mg/kg.

The specification levels for Ally alcohol, Endothall, 2-Ethoxyethanol, and Propargyl alcohol did not require revision.

Note also that in Table 1 of the Final Rule, the category heading for the Oxygenated Organics was misspelled as "Oxygetes".

17.5 SULFONATED ORGANICS

Sulfonated organics Comparable Fuel Specifications are set in a similar manner to that discussed above for hydrocarbons and oxygenates. Sulfonated organics were not detected in any of the fuel oil samples. Gasoline VOC sulfonated organics, as discussed above, were not used due to high detection limits that were achieved.

Changes to the sulfonated organics comparable fuel specifications include, as shown in Table 17-1:

- The specification level for Carbon Disulfide was listed in the TSD and Final Rule with a minimum required detection limit of 37 mg/kg. This value represented the estimated 99th percentile value for the composite of the No. 2, No. 4 and No. 6 fuel oil samples. The revised value has been entered as the highest observed laboratory detection limit of 39 mg/kg.

- The specification levels for Disulfoton; Ethyl methanesulfonate; Methyl methanesulfonate; Phorate; Tetraethyldithiopyrophosphate; and *O,O,O*-Triethyl phosphorothioate were listed in the TSD and in Table 1 of the Final Rule with a minimum required detection limit of 1900 mg/kg. These values represented the estimated 99th percentile values for the composite of all four fuel types. The revised values have been entered as the highest observed laboratory detection limit of 2400 mg/kg for each compound.

The specification levels for 1,3-Propane sultone and Thiophenol did not require revision.

Also, in Table 1 of the Final Rule, the category heading for the Sulfonated Organics was misspelled as "Sulfoted".

17.6 NITROGENATED ORGANICS

Nitrogenated organics comparable fuel specifications are set in a similar manner to that discussed above for sulfonated organics. Gasoline VOC nitrogenated organics, as discussed above, were not used due to high detection limits that were achieved. Nitrogenated organic compounds were not detected in any of the fuel oil samples. Therefore, the highest observed laboratory detection limit from the semi-volatile organic analyses from all fuel types has been entered into the specification table, as shown in Table 17-1. Specific changes include:

- The specification levels for Acetonitrile, Acrylonitrile, and Methacrylonitrile were listed in the TSD and Final Rule with a minimum required detection limit of 37 mg/kg. These values represented the estimated 99th percentile values for the composite of the No. 2, No. 4 and No. 6 fuel oil samples. The revised values have been entered as the highest observed laboratory detection limit of 39 mg/kg for each compound.

- The specification levels for 2-Acetylaminofluorene (2-AAF); 4-Aminobiphenyl; Aniline; Benzidine; Dibenz[a,j]acridine; *O*,*O*-Diethyl *O*-pyrazinyl phosphorothioate; Dimethoate; *p*-(Dimethylamino)azobenzene; 3,3'-Dimethylbenzidine; α,α-Dimethylphenethylamine; 1,3-Dinitrobenzene; 4,6-Dinitro-*o*-cresol; 2,4-Dinitrophenol; 2,4-Dinitrotoluene; 2,6-Dinitrotoluene; Dinoseb; Diphenylamine; Famphur; Methapyrilene; Methyl parathion; 1-Naphthylamine; 2-Naphthylamine; 4-Nitroaniline; Nitrobenzene; *p*-Nitrophenol; 5-Nitro-*o*-toluidine; N-Nitrosodi-n-butylamine; N-Nitrosodiethylamine; N-Nitrosodiphenylamine; –Nitroso-N-methylethylamine; N-Nitrosomorpholine; N-Nitrosopiperidine; N-Nitrosopyrrolidine; Parathion; Phenacetin; 1,4-Phenylene diamine; 2-Picoline; and Pyridine were listed in the TSD and final rule with a minimum required detection limit of 1900 mg/kg. These values represented the estimated 99th percentile values for the composite of all four fuel types. The revised values have been entered as the highest observed laboratory detection limit of 2400 mg/kg for each compound.

- The specification level for *o*-Toluidine was listed in the TSD and Final Rule with a minimum required detection limit of 2200 mg/kg. This value represented the estimated 99th percentile value. The revised value has been entered as the highest observed laboratory detection limit of 2400 mg/kg.

- The specification level for 1,3,5-Trinitrobenzene was listed in the TSD and Final Rule with a minimum required detection limit of 2000 mg/kg. This value represented the estimated 99th percentile value. The revised value has been entered as the highest observed laboratory detection limit of 2400 mg/kg.

The specification level for 4-Aminopyridine; 3,3'-Dimethoxybenzidine; Ethyl carbamate; Ethylenethiourea; Methomyl; 2-Methyllactonitrile; MNNG; Nicotine; 2-Nitropropane; –Phenylthiourea; Propylthiouracil; Strychnine; Thioacetamide; Thiofanox; Thiourea; Toluene-2,4-diamine; Toluene-2,6-diamine and *p*-Toluidine did not require revision.

17.7 HALOGENATED ORGANICS

Halogenated organics comparable fuel specifications are set in a similar manner to that discussed above for sulfonated organics. Gasoline VOC halogenated organics, as discussed above, were not used due to high detection limits that were achieved. Halogenated organic compounds were not detected in any of the fuel oil samples. Therefore, the highest observed laboratory detection limit from the semi-volatile organic analyses from all fuel types has been entered into the specification table, as shown in Table 17-1. Specific changes include:

- The specification levels for Allyl chloride; Bromoform; Bromomethane; Carbon tetrachloride; Chlorobenzene; 2-Chloroethyl vinyl ether; Chloroform; Chloromethane; Chloroprene; 1,2-Dibromo-3-chloropropane; Dichlorodifluoromethane; 1,2-Dichloroethane; 1,1-Dichloroethylene; 1,2-Dichloropropane; *cis*-1,3-Dichloropropene; *trans*-1,3-Dichloropropene; Ethylidene dichloride; Methylene chloride; Methyl iodide; Pentachloroethane; 1,1,2,2-Tetrachloroethane; Tetrachloroethene; 1,1,1-Trichloroethane; 1,1,2-Trichloroethane; Trichloroethene; Trichlorofluoromethane; 1,2,3-Trichloropropane; and Vinyl chloride were listed in the TSD and Final Rule with a minimum required detection limit of 37 mg/kg. These values represented the estimated 99th percentile values for the composite of the No. 2, No. 4 and No. 6 fuel oil samples. The revised values have been entered as the highest observed laboratory detection limit of 39 mg/kg for each compound.

- The specification levels for Aramite; bis-(2chloroethyl)ether; 4-Bromophenyl phenyl ether; *p*-Chloroaniline; Chlorobenzilate; *p*-Chloro-*m*-cresol; 2-Chloronaphthalene; 2-Chlorophenol; Diallate; 1,2-Dichlorobenzene; 1,3-Dichlorobenzene; 1,4-Dichlorobenzene; 3,3-Dichlorobenzidine; Dichloromethoxy ethane; 2,4-Dichlorophenol; 2,6-Dichlorophenol; Hexachlorobenzene; Hexachloro-1,3-butadiene; Hexachlorocyclopentadiene; Hexachloroethane; Hexachloropropene; Isodrin; Pentachlorobenzene; Pentachloronitrobenzene; Pentachlorophenol; Pronamide; 1,2,4,5-Tetrachlorobenzene; 2,3,4,6-Tetrachlorophenol; 1,2,4-Trichlorobenzene; 2,4,5-Trichlorophenol; and 2,4,6-Trichlorophenol were listed in the TSD and Final Rule with a minimum required detection limit of 1900 mg/kg. These values represented the estimated 99th percentile values for the composite of all four fuel types. The revised values have been entered as the highest observed laboratory detection limit of 2400 mg/kg for each compound.

- The specification level for Kepone was listed in the TSD and Final Rule with a minimum required detection limit of 3600 mg/kg. This value represented the estimated 99th percentile value. The revised value has been entered as the highest observed laboratory detection limit of 4700 mg/kg.

- The specification level for Hexachlorophene was listed in the TSD and Final Rule with a minimum required detection limit of 1000 mg/kg. The revised value has been entered as the highest observed laboratory detection limit of 59,000 mg/kg.

The specification level for Benzal chloride; Benzyl chloride; Chlordane; 2,4-D; 1,3-Dichloro-2-propanol; Endosulfan I; Endosulfan II; Endrin; Endrin aldehyde; Endrin ketone; Epichlorohydrin; 2-Fluoroacetamide; Heptachlor; Heptachlor epoxide; Lindane; 4,4'-Methylene-bis-(2-chloroaniline); Silvex; and 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin did not require revision.

TABLE 17-1. COMPARABLE FUEL SPECIFICATION

Chemical Name	CAS Number	Composite Value (mg/kg)	Heating Value (BTU/lb)	Concentration Limit (mg/kg at 10,000 BTU/lb)	Minimum Required Detection Limit (mg/kg)
Total Nitrogen as N	NA	9000	18400	4900	-
Total Halogens as Cl	NA	1000	18400	540	-
Total Organic Halogens as Cl	NA			25 or individual halogenated organics listed below	-
Polychlorinated biphenyls, total [Arocolors, total][a]	1336-36-3	ND		non-detect	1.4
Cyanide, total	57-12-5	ND		non-detect	1.0
Metals					
Antimony, total	7440-36-0	ND		12	-
Arsenic, total	7440-38-2	ND		0.23	-
Barium, total	7440-39-3	ND		23	-
Beryllium, total	7440-41-7	ND		1.2	-
Cadmium, total	7440-43-9	ND		1.2	-
Chromium, total	7440-47-3	ND		2.3	-
Cobalt	7440-48-4	ND		4.6	-
Lead, total	7439-92-1	57	18100	31	-
Manganese	7439-96-5	ND		1.2	-
Mercury, total	7439-97-6	ND		0.25	-
Nickel, total	7440-02-0	106	18400	58	-
Selenium, total	7782-49-2	ND		0.23	-
Silver, total	7440-22-4	ND		2.3	-
Thallium, total	7440-28-0	ND		23	-
Hydrocarbons					
Benzo[a]anthracene	56-55-3	ND		2400	-
Benzene	71-43-2	8000	19600	4100	-
Benzo[b]fluoranthene	205-99-2	ND		2400	-
Benzo[k]fluoranthene	207-08-9	ND		2400	-
Benzo[a]pyrene	50-32-8	ND		2400	-
Chrysene	218-01-9	ND		2400	-
Dibenzo[a,h]anthracene	53-70-3	ND		2400	-
7,12-Dimethylbenz[a]anthracene	57-97-6	ND		2400	-
Fluoranthene	206-44-0	ND		2400	-
Indeno(1,2,3-cd)pyrene	193-39-5	ND		2400	-
3-Methylcholanthrene	56-49-5	ND		2400	-

Chemical Name	CAS Number	Composite Value (mg/kg)	Heating Value (BTU/lb)	Concentration Limit (mg/kg at 10,000 BTU/lb)	Minimum Required Detection Limit (mg/kg)
Naphthalene	91-20-3	6200	19400	3200	-
Toluene	108-88-3	69000	19400	36000	-
Oxygenates					
Acetophenone	98-86-2	ND		2400	-
Acrolein	107-02-8	ND		39	-
Allyl alcohol	107-18-6	ND		30	-
Bis(2-ethylhexyl)phthalate [Di-2-ethylhexyl phthalate]	117-81-7	ND		2400	-
Butyl benzyl phthalate	85-68-7	ND		2400	-
o-Cresol [2-Methyl phenol]	95-48-7	ND		2400	-
m-Cresol [3-Methyl phenol]	108-39-4	ND		2400	-
p-Cresol [4-Methyl phenol]	106-44-5	ND		2400	-
Di-n-butyl phthalate	84-74-2	ND		2400	-
Diethyl phthalate	84-66-2	ND		2400	-
2,4-Dimethylphenol	105-67-9	ND		2400	-
Dimethyl phthalate	131-11-3	ND		2400	-
Di-n-octyl phthalate	117-84-0	ND		2400	-
Endothall	145-73-3	ND		100	-
Ethyl methacrylate	97-63-2	ND		39	-
2-Ethoxyethanol [Ethylene glycol monoethyl ether]	110-80-5	ND		100	-
Isobutyl alcohol	78-83-1	ND		39	-
Isosafrole	120-58-1	ND		2400	-
Methyl ethyl ketone [2-Butanone]	78-93-3	ND		39	-
Methyl methacrylate	80-62-6	ND		39	-
1,4-Naphthoquinone	130-15-4	ND		2400	-
Phenol	108-95-2	ND		2400	-
Propargyl alcohol [2-Propyn-1-ol]	107-19-7	ND		30	-
Safrole	94-59-7	ND		2400	-
Sulfonated Organics					
Carbon disulfide	75-15-0	ND		non-detect	39
Disulfoton	298-04-4	ND		non-detect	2400
Ethyl methanesulfonate	62-50-0	ND		non-detect	2400
Methyl methanesulfonate	66-27-3	ND		non-detect	2400
Phorate	298-02-2	ND		non-detect	2400
1,3-Propane sultone	1120-71-4	ND		non-detect	100
Tetraethyldithiopyrophosphate [Sulfotepp]	3689-24-5	ND		non-detect	2400
Thiophenol [Benzenethiol]	108-98-5	ND		non-detect	30

Chemical Name	CAS Number	Composite Value (mg/kg)	Heating Value (BTU/lb)	Concentration Limit (mg/kg at 10,000 BTU/lb)	Minimum Required Detection Limit (mg/kg)
O,O,O-Triethyl phosphorothioate	126-68-1	ND		non-detect	2400
Nitrogenated Organics					
Acetonitrile [Methyl cyanide]	75-05-8	ND		non-detect	39
2-Acetylaminofluorene [2-AAF]	53-96-3	ND		non-detect	2400
Acrylonitrile	107-13-1	ND		non-detect	39
4-Aminobiphenyl	92-67-1	ND		non-detect	2400
4-Aminopyridine	504-24-5	ND		non-detect	100
Aniline	62-53-3	ND		non-detect	2400
Benzidine	92-87-5	ND		non-detect	2400
Dibenz[a,j]acridine	224-42-0	ND		non-detect	2400
O,O-Diethyl O-pyrazinyl phosphorothioate [Thionazin]	297-97-2	ND		non-detect	2400
Dimethoate	60-51-5	ND		non-detect	2400
p-(Dimethylamino)azobenzene [4-Dimethylaminoazobenzene]	60-11-7	ND		non-detect	2400
3,3'-Dimethylbenzidine	119-93-7	ND		non-detect	2400
α,α-Dimethylphenethylamine	122-09-8	ND		non-detect	2400
3,3'-Dimethoxybenzidine	119-90-4	ND		non-detect	100
1,3-Dinitrobenzene [m-Dinitrobenzene]	99-65-0	ND		non-detect	2400
4,6-Dinitro-o-cresol	534-52-1	ND		non-detect	2400
2,4-Dinitrophenol	51-28-5	ND		non-detect	2400
2,4-Dinitrotoluene	121-14-2	ND		non-detect	2400
2,6-Dinitrotoluene	606-20-2	ND		non-detect	2400
Dinoseb [2-sec-Butyl-4,6-dinitrophenol]	88-85-7	ND		non-detect	2400
Diphenylamine	122-39-4	ND		non-detect	2400
Ethyl carbamate [Urethane]	51-79-6	ND		non-detect	100
Ethylenethiourea (2- Imidazolidinethione)	96-45-7	ND		non-detect	110
Famphur	52-85-7	ND		non-detect	2400
Methacrylonitrile	126-98-7	ND		non-detect	39
Methapyrilene	91-80-5	ND		non-detect	2400
Methomyl	16752-77-5	ND		non-detect	57
2-Methyllactonitrile [Acetone cyanohydrin]	75-86-5	ND		non-detect	100

Chemical Name	CAS Number	Composite Value (mg/kg)	Heating Value (BTU/lb)	Concentration Limit (mg/kg at 10,000 BTU/lb)	Minimum Required Detection Limit (mg/kg)
Methyl parathion	298-00-0	ND		non-detect	2400
MNNG (N-Metyl-N-nitroso-N'-nitroguanidine)	70-25-7	ND		non-detect	110
1-Naphthylamine, [α-Naphthylamine]	134-32-7	ND		non-detect	2400
2-Naphthylamine, [β-Naphthylamine]	91-59-8	ND		non-detect	2400
Nicotine	54-11-5	ND		non-detect	100
4-Nitroaniline, [p-Nitroaniline]	100-01-6	ND		non-detect	2400
Nitrobenzene	98-95-3	ND		non-detect	2400
p-Nitrophenol, [p-Nitrophenol]	100-02-7	ND		non-detect	2400
5-Nitro-o-toluidine	99-55-8	ND		non-detect	2400
N-Nitrosodi-n-butylamine	924-16-3	ND		non-detect	2400
N-Nitrosodiethylamine	55-18-5	ND		non-detect	2400
N-Nitrosodiphenylamine, [Diphenylnitrosamine]	86-30-6	ND		non-detect	2400
N-Nitroso-N-methylethylamine	10595-95-6	ND		non-detect	2400
N-Nitrosomorpholine	59-89-2	ND		non-detect	2400
N-Nitrosopiperidine	100-75-4	ND		non-detect	2400
N-Nitrosopyrrolidine	930-55-2	ND		non-detect	2400
2-Nitropropane	79-46-9	ND		non-detect	30
Parathion	56-38-2	ND		non-detect	2400
Phenacetin	62-44-2	ND		non-detect	2400
1,4-Phenylene diamine, [p-Phenylenediamine]	106-50-3	ND		non-detect	2400
N-Phenylthiourea	103-85-5	ND		non-detect	57
2-Picoline [alpha-Picoline]	109-06-8	ND		non-detect	2400
Propylthioracil [6-Propyl-2-thiouracil]	51-52-5	ND		non-detect	100
Pyridine	110-86-1	ND		non-detect	2400
Strychnine	57-24-9	ND		non-detect	100
Thioacetamide	62-55-5	ND		non-detect	57
Thiofanox	39196-18-4	ND		non-detect	100
Thiourea	62-56-6	ND		non-detect	57
Toluene-2,4-diamine [2,4-Diaminotoluene]	95-80-7	ND		non-detect	57

Chemical Name	CAS Number	Composite Value (mg/kg)	Heating Value (BTU/lb)	Concentration Limit (mg/kg at 10,000 BTU/lb)	Minimum Required Detection Limit (mg/kg)
Toluene-2,6-diamine [2,6-Diaminotoluene]	823-40-5	ND		non-detect	57
o-Toluidine	95-53-4	ND		non-detect	2400
p-Toluidine	106-49-0	ND		non-detect	100
1,3,5-Trinitrobenzene, [sym-Trinitobenzene]	99-35-4	ND		non-detect	2400
Halogenated Organics					
Allyl chloride	107-05-1	ND		non-detect	39
Aramite	140-57-8	ND		non-detect	2400
Benzal chloride [Dichloromethyl benzene]	98-87-3	ND		non-detect	100
Benzyl chloride	100-44-77	ND		non-detect	100
bis(2-Chloroethyl)ether [Dichoroethyl ether]	111-44-4	ND		non-detect	2400
Bromoform [Tribromomethane]	75-25-2	ND		non-detect	39
Bromomethane [Methyl bromide]	74-83-9	ND		non-detect	39
4-Bromophenyl phenyl ether [p-Bromo diphenyl ether]	101-55-3	ND		non-detect	2400
Carbon tetrachloride	56-23-5	ND		non-detect	39
Chlordane	57-74-9	ND		non-detect	14
p-Chloroaniline	106-47-8	ND		non-detect	2400
Chlorobenzene	108-90-7	ND		non-detect	39
Chlorobenzilate	510-15-6	ND		non-detect	2400
p-Chloro-m-cresol	59-50-7	ND		non-detect	2400
2-Chloroethyl vinyl ether	110-75-8	ND		non-detect	39
Chloroform	67-66-3	ND		non-detect	39
Chloromethane [Methyl chloride]	74-87-3	ND		non-detect	39
2-Chloronaphthalene [beta-Chloronaphthalene]	91-58-7	ND		non-detect	2400
2-Chlorophenol [o-Chlorophenol]	95-57-8	ND		non-detect	2400
Chloroprene [2-Chloro-1,3-butadiene]	1126-99-8	ND		non-detect	39
2,4-D [2,4-Dichlorophenoxyacetic acid]	94-75-7	ND		non-detect	7.0
Diallate	2303-16-4	ND		non-detect	2400
1,2-Dibromo-3-chloropropane	96-12-8	ND		non-detect	39

Chemical Name	**CAS Number**	**Composite Value (mg/kg)**	**Heating Value (BTU/lb)**	**Concentration Limit (mg/kg at 10,000 BTU/lb)**	**Minimum Required Detection Limit (mg/kg)**
1,2-Dichlorobenzene [o-Dichlorobenzene]	95-50-1	ND		non-detect	2400
1,3-Dichlorobenzene [m-Dichlorobenzene]	541-73-1	ND		non-detect	2400
1,4-Dichlorobenzene [p-Dichlorobenzene]	106-46-7	ND		non-detect	2400
3,3'-Dichlorobenzidine	91-94-1	ND		non-detect	2400
Dichlorodifluoromethane [CFC-12]	75-71-8	ND		non-detect	39
1,2-Dichloroethane [Ethylene dichloride]	107-06-2	ND		non-detect	39
1,1-Dichloroethylene [Vinylidene chloride]	75-35-4	ND		non-detect	39
Dichloromethoxy ethane [Bis(2-chloroethoxy)methane	111-91-1	ND		non-detect	2400
2,4-Dichlorophenol	120-83-2	ND		non-detect	2400
2,6-Dichlorophenol	87-65-0	ND		non-detect	2400
1,2-Dichloropropane [Propylene dichloride]	78-87-5	ND		non-detect	39
cis-1,3-Dichloropropylene	10061-01-5	ND		non-detect	39
trans-1,3-Dichloropropylene	10061-02-6	ND		non-detect	39
1,3-Dichloro-2-propanol	96-23-1	ND		non-detect	30
Endosulfan I	959-98-8	ND		non-detect	1.4
Endosulfan II	33213-65-9	ND		non-detect	1.4
Endrin	72-20-8	ND		non-detect	1.4
Endrin aldehyde	7421-93-4	ND		non-detect	1.4
Endrin Ketone	53494-70-5	ND		non-detect	1.4
Epichlorohydrin [1-Chloro-2,3-epoxy propane]	106-89-8	ND		non-detect	30
Ethylidene dichloride [1,1-Dichloroethane]	75-34-3	ND		non-detect	39
2-Fluoroacetamide	640-19-7	ND		non-detect	100
Heptachlor	76-44-8	ND		non-detect	1.4
Heptachlor epoxide	1024-57-3	ND		non-detect	2.8
Hexachlorobenzene	118-74-1	ND		non-detect	2400

Chemical Name	CAS Number	Composite Value (mg/kg)	Heating Value (BTU/lb)	Concentration Limit (mg/kg at 10,000 BTU/lb)	Minimum Required Detection Limit (mg/kg)
Hexachloro-1,3-butadiene [Hexachlorobutadiene]	87-68-3	ND		non-detect	2400
Hexachlorocyclopentadiene	77-47-4	ND		non-detect	2400
Hexachloroethane	67-72-1	ND		non-detect	2400
Hexachlorophene	70-30-4	ND		non-detect	59000
Hexachloropropene [Hexachloropropylene]	1888-71-7	ND		non-detect	2400
Isodrin	465-73-6	ND		non-detect	2400
Kepone [Chlordecone]	143-50-0	ND		non-detect	4700
Lindane [gamma-BHC] [gamma-Hexachlorocyclohexane]	58-89-9	ND		non-detect	1.4
Methylene chloride [Dichloromethane]	75-09-2	ND		non-detect	39
4,4'-Methylene-bis(2-chloroaniline)	101-14-4	ND		non-detect	100
Methyl iodide [Iodomethane]	74-88-4	ND		non-detect	39
Pentachlorobenzene	608-93-5	ND		non-detect	2400
Pentachloroethane	76-01-7	ND		non-detect	39
Pentachloronitrobenzene [PCNB] [Quintobenzene] [Quintozene]	82-68-8	ND		non-detect	2400
Pentachlorophenol	87-86-5	ND		non-detect	2400
Pronamide	23950-58-5	ND		non-detect	2400
Silvex [2,4,5-Trichlorophenoxypropionic acid]	93-72-1	ND		non-detect	7.0
2,3,7,8-Tetrachlorodibenzo-p-dioxin [2,3,7,8-TCDD]	1746-01-6	ND		non-detect	30
1,2,4,5-Tetrachlorobenzene	95-94-3	ND		non-detect	2400
1,1,2,2-Tetrachloroethane	79-34-5	ND		non-detect	39
Tetrachloroethylene [Perchloroethylene]	127-18-4	ND		non-detect	39
2,3,4,6-Tetrachlorophenol	58-90-2	ND		non-detect	2400
1,2,4-Trichlorobenzene	120-82-1	ND		non-detect	2400
1,1,1-Trichloroethane [Methyl chloroform]	71-55-6	ND		non-detect	39
1,1,2-Trichloroethane [Vinyl trichloride]	79-00-5	ND		non-detect	39
Trichloroethylene	79-01-6	ND		non-detect	39

Chemical Name	**CAS Number**	**Composite Value (mg/kg)**	**Heating Value (BTU/lb)**	**Concentration Limit (mg/kg at 10,000 BTU/lb)**	**Minimum Required Detection Limit (mg/kg)**
Trichlorofluoromethane [Trichlormonofluoromethane]	75-69-4	ND		non-detect	39
2,4,5-Trichlorophenol	95-95-4	ND		non-detect	2400
2,4,6-Trichlorophenol	88-06-2	ND		non-detect	2400
1,2,3-Trichloropropane	96-18-4	ND		non-detect	39
Vinyl Chloride	75-01-4	ND		non-detect	39

NA - Not Applicable
ND - Non-Detect

REFERENCES

References for Chapter 2

Dellinger, B., J.L. Torres, W.A. Rubey, et al., "Determination of Thermal Decomposition Properties of Selected Hazardous Organic Compounds," *Hazardous Waste and Hazardous Materials*, Vol. 1, No. 2, pp.137-157, 1984.

EER (Energy and Environmental Research Corporation), "State-of-the-Art Assessment of Medical Waste Thermal Treatment," Prepared Under EPA Contract No. 68-03-3365, Prepared for U.S. EPA Risk Reduction Engineering Laboratory, June 15, 1990.

EER (Energy and Environmental Research Corporation), "Dioxins/Furans, HCl, Cl_2, and Related Testing at a Hazardous Waste Burning Light-Weight Aggregate Kiln," Report to the EPA under Contract 68-D2-0164, Work Assignment 4-07, October 1997.

U.S.EPA, "Operation and Maintenance Manual for Electrostatic Precipitators," EPA AEERL ORD, EPA/625/1-85/017, September 1985.

U.S. EPA, "Handbook: Control Technologies for Hazardous Air Pollutants," EPA ORD, EPA/625/6-91/014, June 1991.

U.S. EPA, "Technical Implementation Document for EPA's Boiler and Industrial Furnace Regulations," U.S. EPA Office of Solid Waste and Emergency Response, Washington, DC, EPA/530-R-92-01, March 1992.

References for Chapter 3

Addink, R., and K. Olie, "Mechanisms of Formation and Destruction of Polychlorinated Dibenzo-p-dioxins and Dibenzofurans in Heterogeneous Systems," *Environmental Science and Technology*, Vol. 29, No. 6, pp. 1425-1435, 1995.

Altwicker, E.R. "Relative Rates of Formation of Polychlorinated Dioxins and Furans from Precursor and De Novo Reactions," *Chemosphere*, Vol. 33, No. 10, pp. 1897-1904, 1996.

De Fre, R. and T. Rymen, "PCDD and PCDF Formation from Hydrocarbon Combustion in the Presence of Hydrogen Chloride," *Chemosphere*, Vol. 19, pp. 331-336, 1989.

EER (Energy and Environmental Research Corporation), "Emissions Testing of Ash Grove Cement Company Foreman Arkansas Waste Derived Fuel Facility Cement Kiln No. 3," Report to the EPA under Contract 68-D2-0164, Work Assignment 2-07, 1995.

EER (Energy and Environmental Research Corporation), "Dioxins/Furans, HCl, Cl_2, and Related Testing at a Hazardous Waste Burning Light-Weight Aggregate Kiln," Report to the EPA under Contract 68-D2-0164, Work Assignment 4-07, October 1997.

Fangmark, I., B. Stromberg, N. Berge, and C. Rappe, "Influence of Postcombustion Temperature Profiles on the Formation of PCDDs, PCDFs, PCBzs, and PCBs in a Pilot Incinerator," *Environmental Science and Technology*, Vol. 28, No. 4, pp. 624-629, 1994.

Fangmark, I., B. van Bavel, S. Marklund, B. Stromberg, N. Berge, and C. Rappe, "Influence of Combustion Parameters on the Formation of Polychlorinated Dibenzo-p-dioxins, Dibenzofurans, Benzenes, and Biphenyls and Polyaromatic Hydrocarbons in a Pilot Incinerator," *Environmental Science and Technology,* Vol. 27, No. 8, pp. 1602-1610, 1993.

Frankenhaeuser, M., Manninen, H., Koho, I., et al., "Organic Emissions from Co Combustion of Mixed Plastics with Coal in a Bubbling Fluidized Bed Boiler," *Chemosphere,* Vol. 27, Nos. 1-3, pp. 309-316, 1993.

Gullett, B.K., K.R. Bruce, and L.O. Beach, "The Effect of Metal Catalysts on the Formation of Polychlorinated Dibenzo-p-dioxin and Polychlorinated Dibenzofuran Precursors," *Chemosphere*, Vol. 20, Nos. 10-12, pp. 1945-1952, 1990.

Gullett, B., K. Bruce, and L. Beach, "Effect of Sulfur Dioxide on the Formation Mechanism of Polychlorinated Dibenzodioxin and Dibenzofuran in Municipal Waste Combustors," *Environmental Science and Technology*, Vol. 26, No. 10, 1992.

Gullett, B.K., P.M. Lemieux, and J.E. Dunn, "Role of Combustion and Sorbent Parameters in Prevention of Polychlorinated Dibenzo-p-dioxin and Polychlorinated Dibenzofuran Formation during Waste Combustion," *Environmental Science and Technology*, Vol. 28, No. 1, pp. 107-118, 1994.

Gullett, B.K. and K. Raghunathan, "Observations on the Effect of Process Parameters on Dioxin/Furan Yield in Municipal Waste and Coal Systems," *Chemosphere*, Vol. 34, Nos. 5-7, pp. 1027-1032, 1997.

Hinton, W.S. and A. M. Lane, "Characteristics of Municipal Solid Waste Incinerator Fly Ash Promoting the Formation of Polychlorinated Dioxins," *Chemosphere*, Vol. 22, pp. 473-483, 1991.

Horler, S., and C. Clements, "Commercial Scale Dioxin Inhibition Test Private at a Waste to Energy Plant -- Switzerland," *Proceedings of the 1994 International Incineration Conference*, Houston, Texas, pp. 237- 241, May 9-13, 1994.

Ismo, H., T. Kari, and R. Juhani, "Formation of Aromatic Chlorinated Compounds Catalyzed by Copper and Iron," *Chemosphere*, Vol. 34, No. 12, pp. 2649-2662, 1997.

Johnke, B. and E. Stelzner, "Results of the German Dioxin Measurement Programme at MSW Incinerators," *Waste Management and Research*, Vol. 10, pp. 345-355, 1992.

Kilgroe, J., L. Nelson, P. Schindler, and W. Lanier, "Combustion Control of Organic Emissions from Municipal Waste Combustors," *Combustion Science and Technology*, Vol. 74, pp. 223-244, 1990.

Konduri, R. and E. Altwicker, "Analysis of Time Scales Pertinent to Dioxin/Furan Formation on Fly Ash Surfaces in Municipal Solid Waste Incinerators," *Chemosphere,* Vol. 28, No. 1, pp. 23-45, 1994.

Lenoir, D., A. Kaune, O. Hutziner, et al., "Influence of Operating Parameters and Fuel Type on PCDD/PCDF Emissions From a Fluidized Bed Incinerator," *Chemosphere*, Vol. 23, Nos. 8-10, pp. 1491-1500, 1991.

Lindbauer, R., F. Wurst, and T. Prey, "Combustion Dioxin Suppression in Municipal Solid Waste Incineration with Sulphur Additives," *Chemosphere*, Vol. 25, Nos. 7-10, pp. 1409 1414, 1992.

Manscher, O., N. Heidam, et al., "The Danish Incinerator Dioxin Study: Part I," *Chemosphere*, Vol. 20, Nos. 10-12, pp. 1779-1784, 1990.

Naikwadi, K.P., and F.W. Karasek, "Prevention of PCDD Formation in MSW Incinerators by Inhibition of Catalytic Activity of Fly Ash Produced," *Chemosphere*, Vol. 19, Nos. 1-6, pp. 299-304, 1989.

Nottrodt, A., U. Duwel, and K. Ballschmiter, "The Influence of Increased Excess Air on the Formation of PCDD/PCDF in Municipal Waste Incineration Plant," *Chemosphere*, Vol. 20, Nos. 10-12, pp. 1847-1854, 1990.

Rigo, H.G., A. Chandler, and S. Lanier, "The Relationship Between Chlorine in Waste Streams and Dioxin Emissions from Combustion," ASME, 1995.

Takacs, L. and G.L. Moilanen, "Simultaneous Control of PCDD/PCDF, HCl, and NO_x Emissions from Municipal Solid Waste Incinerators with Ammonia Injection," *Journal of the Air and Waste Management Association*, Vol. 41, No. 5, pp. 716-722, 1991.

Visalli, J.R., "A Comparison of Some Results from the Combustion - Emissions Test Programs at the Pittsfield, Prince Edward Island, and Peekskill Municipal Solid Waste Incinerators," *Journal of the Air Pollution Control Association,* Vol. 37, No. 12, December 1987.

Vogg, H., and L. Steiglitz, "Thermal Behavior of PCDD/PCDF in Fly Ash from Incinerators," C*hemosphere*, Vol. 15, Nos. 9-12, pp. 1373-1378, 1986.

References for Chapter 4

U.S. EPA, "Guidance on Setting Permit Conditions and Reporting Trial Burn Results, Volume II of the Hazardous Waste Incineration Guidance Series," U.S. EPA Office of Solid Waste and Emergency Response, Washington, DC, EPA/625/6-89/019, January 1989.

U.S. EPA, "Technical Implementation Document for EPA's Boiler and Industrial Furnace Regulations," U.S. EPA Office of Solid Waste and Emergency Response, Washington, DC, EPA/530-R-92-01, March 1992.

U.S. EPA, "Waste Analysis Guidance for Facilities that Burn Hazardous Wastes Draft," Enforcement and Compliance Assurance (2224A), EPA 530-R-94-019, October 1994.

U.S. EPA, "Waste Analysis at Facilities that Generate, Treat, Store, and Dispose of Hazardous Waste: A Guidance Manual," U.S. EPA Office of Solid Waste and Emergency Response, Washington, DC, 9938.4-03, April 1994a.

U.S. EPA, "Fabric Filter Bag Leak Detection Guidance," EPA Office of Air Quality Planning and Standards, EPA-454/R-98-015, September 1997.

White, H.J., *Industrial Electrostatic Precipitation*, Addison-Wesley Publishing, Reading Massachusetts, 1963.

References for Chapter 5

GRI, "Characterization and Measurement of Natural Gas Trace Constituents, Volume II, Natural Gas Survey," Gas Research Institute, GRI-94/0243.2, January 1995.

References for Chapter 6

Barton, R.G., W.D. Clark, and W.R. Seeker, "Fate of Metals in Waste Combustion Systems," *Journal of Combustion Science and Technology*, Vol. 74, pp. 327-342, 1990.

Clark, W., and R.G. Rizeq, "Evaluation of Maximum Temperature Limit as a BIF Compliance Parameter for Cement Kilns," EPA Contract 68-CO-0094, Prepared for U.S. EPA Office of Solid Waste, September 27, 1991.

Energy and Environmental Research Corporation (EER), "Relationship and Surrogate Summaries for Major Combustion Systems," Report to the EPA under Contract 68-D2-0164, 1994.

U.S. EPA, "Technical Implementation Document for EPA's Boiler and Industrial Furnace Regulations," U.S. EPA Office of Solid Waste and Emergency Response, Washington, DC, EPA/530-R-92-01, March 1992.

Wu, B., K.K. Jaanu, and F. Shadman, "Multi-functional Sorbents for the Removal of Sulfur and Metallic Contaminants from High-temperature Gases," *Environmental Science and Technology*, Vol. 29, No. 6, pp. 1660-1665, 1995.

References for Chapter 8

Kroll, P.J. and R.C. Chang, "The Incineration System Thermal Siphon Effect," *Environmental Progress*, Vol. 10, No. 1, 1991.

References for Chapter 9

U.S. EPA, "Risk Assessment for the Waste Technologies Industries (WTI) Hazardous Waste Incineration Facility (East Liverpool, Ohio)," EPA-905-R97-002, May 1997.

References for Chapter 10

U.S. EPA, "Test Methods for Evaluating Solid Wastes: Physical/Chemical Methods, SW-846, Third Edition," U.S. EPA Office of Solid Waste and Emergency Response, November 1986.

U.S. EPA, "Guidance on Setting Permit Conditions and Reporting Trial Burn Results, Volume II of the Hazardous Waste Incineration Guidance Series," U.S. EPA Office of Solid Waste and Emergency Response, Washington, DC, EPA/625/6-89/019, January 1989.

U.S. EPA, "Technical Implementation Document for EPA's Boiler and Industrial Furnace Regulations," U.S. EPA Office of Solid Waste and Emergency Response, Washington, DC, EPA/530-R-92-01, March 1992.

U.S. EPA, "Operational Parameters for Hazardous Waste Combustion Devices," U.S. EPA Office of Research and Development, Cincinnati, OH, EPA/625/R-93/008, October 1993.

References for Chapter 12

Bechtel Jacobs for U.S. DOE Office of Environmental Management, "Field Test to Determine Deployment Potential of Three Candidate Multimetal Monitoring Techniques at the TSCA Incinerator," BJC/OR-27, June, 1998.

Buhne, K. W. and L. Duwel (TÜV), "Recording Dust Measurements in the Cement Industry with Sick Company's RM4 Device for Measuring Smoke Density," circa 1972, 19 pp.

French, N.B., et al., "State of the Art Mercury CEMS for Hazardous and Mixed Waste Incineration Applications," *Environmental Science and Technology*, February 1999.

Roberson, R.L., G.C. Clark, and C.E. Dene, "Evaluation of Continuous Particulate Matter (PM) Monitors for Coal-Fired Utility Boilers with Electrostatic Precipitators, at 92nd Annual AWMA Meeting, St. Louis, June 1999.

TÜV, "Report over the Aptitude Test of the Dust Content Measuring Equipment of the Type CPM 1001 from the Company BHA Group GmbH," Germany, 1997, 58 pp.

References for Chapter 14

Heumann, W.L., *Industrial Air Pollution Control Systems*, McGraw-Hill, 1997.

McKenna, J.D. and Turner, J.H., *Fabric Filter - Baghouses I, Theory Design and Selection*, ETS, Inc., 1989.

U.S. EPA, *Wet Scrubber Inspection and Evaluation Manual*, EPA 340/1-83-002, NTIS PB 85-149375, September 1983.

U.S. EPA, *Operation and Maintenance Manual for ESPs*, EPA/625/1-85/017, September 1985.

U.S. EPA, *Operation and Maintenance Manual for Fabric Filters*, EPA/625/1-86/020, June 1986.

U.S. EPA, *Handbook: Operation and Maintenance of Hospital Medical Waste Incinerators*, EPA/625/6-89/024, January 1990.

References for Chapter 16

U.S. EPA, "Test Methods for Evaluating Solid Wastes: Physical/Chemical Methods, SW-846, Third Edition," U.S. EPA Office of Solid Waste and Emergency Response, November 1986.

APPENDIX A

CEMS SURVEYS

Surveys of state-of-the-art technology for continuous monitoring of PM, mercury, acid gases, multi-metals, and organic compounds are described in the following sections. These surveys draw primarily upon direct communications with vendors and developers, and upon product literature. Each survey provides a discussion of the technical approaches available or being pursued to make the measurement, the capabilities, advantages, and disadvantages of each approach, the developmental status of each approach, and the certification testing history, if any, of each approach. Each survey then ends with an assessment of the feasibility of using CEMS for compliance monitoring.

A.1 CEMS FOR PARTICULATE MATTER

A.1.1 Introduction

Current measurements of particulate matter are made using EPA Method 5. Method 5 involves isokinetic sampling of the stack flow and collection of particles on a filter. The filter is then weighed to determine the mass emission rate of particulate matter. This method is a manual method and involves time consuming analysis that provides a direct measurement of the mass of emitted particulate matter (PM). A need therefore exists for a PM measurement technology that is continuous, automatic, and provides real-time analysis. The output of such a PM CEMS should be indicative of the PM mass emission rate.

Potential PM CEMS employing a variety of measurement principles are currently commercially available. None of these devices have received EPA approval for stack PM mass emissions monitoring. This is due to the fact that most of these devices actually measure secondary properties of particles from which the mass may be inferred rather than making a direct measurement of mass. For example, optical methods measure the attenuation or scattering of light due to the presence of PM. The measurement is directly related to the volume of PM present, although in general it also depends on the PM size distribution and composition. The resultant volume measurement must then be related to mass by assuming a particle density. This is typically accomplished using a site specific calibration against Method 5. Inherent in this approach is the assumption that the relation between the measured response and PM mass loading does not change with time.

Commercially available PM CEMS are summarized in Table A-1. This table includes all of the approaches to a PM CEMS identified based on available information. Specific manufacturers of each type of device are listed in the table as representatives of their respective technologies, thus this table is not intended to be a comprehensive compilation of vendors. Device types listed in the table are categorized as O for optical, E for extractive (PM is sampled isokinetically), and P for probe (particles make physical contact with a probe inserted into the flow). The oscillating element system (the only direct mass measurement system) is designed for ambient sampling, and is probably not suitable for application to stack sampling for the reasons discussed in Section A.2.10. All of the other approaches are available for stack sampling, thus there is no development time connected with these technologies.

In the sections that follow, the technologies identified above are assessed in terms of their measurement ranges and sensitivities to parameters other than particulate mass loading which can give rise to biases in the measurement. In addition, the German experience with light scattering CEMS for compliance monitoring of PM emissions is discussed based on a fact finding trip to Germany and a TUV certification report for the Sick RM200.

A.1.2 Opacity Monitors

A variety of optical approaches to the problem of particulate mass measurement exist. The simplest is opacity monitoring, in which the attenuation of a light beam caused by scattering and absorption is measured. This attenuation is dependent on both the composition and size of the particles (Jahnke, 1984). Studies have shown that opacity can be correlated with mass emissions, however, concern about the stability of the correlation has prevented the use of opacity for the monitoring of mass emissions in the US (Conner and Knapp, 1988 and Conner et al., 1979). Instead, monitoring opacity for compliance purposes without any attempt to relate it to actual PM emissions is required in instances where continuous monitoring is desired. Opacity monitors are the least sensitive of the various optical approaches, with a typical range of applicability of 0.02 to 4 gr/dscf, due to the fact that a small change (attenuation) in a large quantity (the light beam transmitted across the duct) is measured (Monitor Labs, 1994).

Disadvantages:

- Insufficient sensitivity

Advantages

- Established technology, reliable operation

A.1.3 Time Dependent Optical Attenuation

A variant of the opacity meter is commercially available from BHA. This instrument monitors the time dependent component of the transmission signal, essentially measuring the change in transmission as each particle passes through the beam (Bock, 1993 and BHA Group, Inc., 1994). This approach is not sensitive to buildup on the windows, and has an upper limit on particle loading of about 4 gr/ft^3. The lower detection limit is about 4×10^{-6} gr/ft^3. The particle size range over which the instrument can effectively make measurements is 0.3 to over 75 µm. This is a cross-stack measurement requiring two points of access.

Advantages:

- Excellent sensitivity
- Continuous
- In-situ

Disadvantages:

- Sensitive to particle size distribution and particle characteristics
- Does not measure mass, must be calibrated against Method 5

A.1.4 Forward Light Scattering

Techniques that monitor particle loading by measuring the scattered light in addition to the transmitted intensity are also available. When the light scattered by many particles present in the beam is measured, the technique is referred to as ensemble scattering. Insitec has a system known as TESS (Transform method for Extinction-Scattering with Spatial resolution) that operates on this principle. A probe containing the optics is inserted into the flow, and the forward light scattering from particles passing through a slot in the probe is measured. The particle size range of the device is specified as submicron to 20 microns, and is specified as being independent of particle size and composition. In fact, the measured scattering is used to calculate an average particle size independent of knowledge of the particle size distribution. Combined with the extinction measurement, total particle volume can then be calculated. To obtain particle mass, the technique must be calibrated against Method 5. The range of PM loadings for which the method is applicable is roughly 0.006 to greater than 1 gr/dscf. Insertion of a probe requires only one point of access to the stack (Insitec Measurement Systems, 1994).

Advantages:

- Continuous
- In-situ
- Compared to other optical methods, reduced sensitivity to particle distribution and particle characteristics

Disadvantages:

- Less sensitive than other light scattering approaches
- May not detect particles < 1 µm
- Some sensitivity to particle distribution and particle characteristics, especially if particle size falls outside of the 1 to 20 µm range
- Does not measure mass, must be calibrated against Method 5

A.1.5 Backward Light Scattering

An instrument using back scattered light is available from Environmental Systems Corporation. This instrument, known as the P5A particulate monitor, has a roughly constant response to particles in the 0.1 to 10 µm range. The response of the instrument does depend on the optical properties of the particles, and a mass measurement is made by calibration against Method 5. This instrument has a PM range of 0.0005 to 8 gr/dscf and requires only one point of access to the stack (Environmental Systems Corporation, 1994).

Advantages:

- Good sensitivity
- Sensitive to particles as small as 0.1 µm
- Continuous
- In-situ

Disadvantages:

- Sensitive to particle distribution and particle characteristics, especially if particle size falls outside of the 0.1 to 10 µm range
- Does not measure mass, must be calibrated against Method 5

A.1.6 <u>90^o Light Scattering</u>

A German company, Sick Optic, makes a PM CEMS based on light scattering at 90^o. This device, the RM200, only requires one point of access to the stack, and has a PM detection limit of $2x10^{-6}$ gr/dscf (Sick Optic-Electronic, Inc., 1994). The particle size range to which the device is sensitive is 0.1 to 50 µm. This device is likely to be sensitive to particle size distribution and particle properties, and requires site specific calibration in order to make PM mass emission measurements. It use has been approved by the German equivalent of the EPA, and it has passed the German TUV standards. It is installed on between one and two hundred stacks. A site specific calibration is required in each case in order to provide PM mass emissions.

Advantages:

- Excellent sensitivity
- Sensitive to particles as small as 0.1 µm
- Continuous
- In-situ

Disadvantages:

- Sensitive to particle distribution and particle characteristics, although the Germans have evaluated the performance and found it to be adequate
- Does not measure mass, must be calibrated against Method 5

A.1.7 <u>Triboelectric Effect</u>

The triboelectric effect is the transfer of electric charge when particles impact on a dissimilar object. The measurement thus consists of inserting a metal rod into the flow and measuring the electric current induced by the particles as they flow past and hit the rod. This technology is currently available from Auburn International for monitoring flow upsets and bag breakthroughs (Auburn International Inc., 1994). When calibrated against Method 5, particle mass flow rate can be estimated (Averdieck, 1987). The magnitude of the effect is dependent on composition, size, flow velocity (small particles follow streamlines and do not impact the probe), and resistivity (which is highly dependent on humidity). Response is also sensitive to conditioning of the probe surface through the buildup of deposits and/or erosion (Gnyp et al., 1979, John, 1975, John et al., 1980, and Gruber and Bastness, 1973).

Advantages:

- Excellent sensitivity (detection limit $5x10^{-5}$ gr/dscf)
- Sensitive to particles as small as 0.5 µm
- Continuous
- In-situ

Disadvantages:

- Sensitive to flow velocity, particle size distribution and particle characteristics
- Does not measure mass, must be calibrated against Method 5
- Very sensitive to changes in humidity

A.1.8 Beta Transmissivity

A French company, Emissions SA, makes a beta gauge (Beta 5M) for stack sampling of PM emissions. This device uses a heated sampling probe to obtain an isokinetic sample (isokinetic sampling is maintained automatically). The sample is collected on a filter, which, at the end of the sampling period, is moved (using a continuous filter tape mechanism) to a measurement location between a carbon 14 beta particle source and a detector. The beta transmission through each blank filter is determined before sampling begins. The sampling duration is programmable and determines the mass concentration detection limit. At high PM loadings it must be kept small enough to prevent sampling excessive amounts of particulate, and is usually set at two minutes for typical applications. Analysis takes six minutes. At the end of each sampling period, the probe nozzle is temporarily closed, opened, and closed again in order to re-entrain any particulate that may have deposited in the probe (Emissions S.A., 1994).

Advantages:

- Excellent sensitivity, DL = $1.7X10^{-6}$ gr/dscf for a one hour sample
- Sensitive to all particles

Disadvantages:

- Extractive: potential problems with fallout of PM in the probe
- Batch sampling, not continuous

A.1.9 Acoustic Energy Monitoring

Jonas Inc. markets a device based on acoustic energy monitoring. In this technique shock waves caused by the impact of particles with a probe inserted into the flow are used to measure particle loading. The device counts the number of impacts and also measures the energy of each impact. This information, coupled with knowledge of the flow velocity, allows calculation of the particle mass (Jonas, Inc., 1994 and Jonas, 1990). Since the probe distorts the flow, changes in flow velocity and particle size distribution will, in principle, change the instrument response.

Advantages:

- Good sensitivity, DL not known, but range specified as 0 to 0.05 gr/dscf
- Continuous
- In-situ

Disadvantages:

- Not as sensitive to small particles less than 10 µm
- Sensitive to flow velocity and particle size distribution
- Does not measure mass, must be calibrated against Method 5

A.1.10 Tapered Oscillating Element Microbalance (TOEM)

Rupprecht and Pataschnick Co., Inc. make an ambient air monitor based on a TOEM. In this technique the natural frequency of oscillation of a beam is measured as particles accumulate on a filter through which the sampled air flow passes (the changing mass changes the frequency of oscillation). This is thus a direct measurement of particle mass. However, the instrument response is humidity and temperature dependent, requiring control of these two parameters. The filter also requires periodic changing: for the device as currently configured, a 0.005 gr/dscf PM loading would require a filter change every two hours with a 1/2 to 2 hour downtime after each filter change. It is questionable whether this device could be made suitable for stack monitoring, and the manufacturer has no current plans to do so (Ruprecht and Pataschnick, 1994).

Advantages:

- Direct measurement of mass
- Excellent sensitivity
- Sensitive to all particles

Disadvantages:

- Extractive: potential problem with PM fallout in the probe
- Frequent downtime for filter change and re-equilibration

A.1.11 Summary

The performance capabilities and issues affecting accuracy of the various PM CEMS are summarized in Table A-2 and Table A-3. Opacity monitors and the tapered oscillating element device have been omitted from the table due to their lack of sensitivity and lack of availability and suitability for stack monitoring, respectively.

The response of light scattering based systems is typically a function of particle size and material properties, although less so than for opacity based systems (Gnyp et al.,1979). Specific devices are designed to have as nearly flat a response as possible over as large a portion of the size range of interest as possible. However, this does not eliminate the potential dependence of the device response on particle size distribution. Demonstration is thus required to show that the variability of particle size distribution of the source does not unduly affect the accuracy of the measurement. Further, the responses of some optical techniques depend to varying extents on the particulate composition (through its effect on the index of refraction of the particulate). Particulate composition also affects the accuracy of all optical approaches through its effect on particle density.

Devices that rely on the contact of particles with a physical probe will also have a response that is dependent on particle size for two reasons. First, smaller particles follow the flow streamlines better than large particles, and will thus tend to impact the probe less frequently. This effect will also depend on flow velocity, and results in the under-sampling of small particles. Second, small particles will have a reduced physical effect when they do impact the probe, and thus there will be a minimum detectable particle size. At what point these effects become important compared to the range of particle size that is actually present will determine the importance of size dependent response in limiting the accuracy of the measurement.

A.1.12 PM CEMS Use in Germany

In the case of PM CEMS, devices are commercially available and installed on stacks world wide. They are installed and used for compliance purposes in Germany. In fact, the Germans have taken the lead in the development, certification, and application of PM CEMS. Therefore, as part of EPA's assessment of PM CEMS for compliance, a fact-finding trip to Germany in November of 1994 was undertaken in order to investigate the nature of the German experience with PM CEMS, their certification procedure, and their use in practice for emissions compliance. The aims of the trip were the following: to bring back an understanding of the German certification process (how exhaustive and rigorous, what is required, etc.); to find out how CEMS are used for compliance in Germany; to asses CEMS reliability; and to examine German data or experience regarding the stability of the CEMS calibrations.

In order to attempt to achieve these aims, Mr. Buhne of TUV Rheinland in Cologne was visited. TUV stands for the German equivalent of "technical inspection agency." TUV, which is a non-profit organization, is mandated by the government to, among other things, perform environmental testing and the certification of CEMS which are used for environmental monitoring. TUV, and Mr. Buhne in particular, have developed both the German manual methods for PM measurement and the certification process for PM CEMS, and Mr. Buhne has extensive experience built up over 20 years with the performance of PM CEMS in the field. The meeting with Mr. Buhne was held on November 8, 1994, and the information that he related during the interview is summarized below.

In the 1960's TUV first investigated CEMS for PM. Eight devices were evaluated, all of which failed to perform satisfactorily. In response, TUV set up a certification system through which the minimum requirements which could be met by the available instruments were established and then were used as the basis for approval of devices. This is accomplished through 3 to 6 months of testing for each instrument, and was originally done for opacity monitoring systems, which are effective at PM loadings down to the 50 mg/m^3 level over a 3 m path length. In 1968 two instruments were approved. In 1972 light scattering devices were first tried, but the results were no better than with opacity monitors. By 1983, however, light scattering systems were approved for ambient monitoring, and by 1984, for stacks. Sigrist made the first PM CEMS based on light scattering. This device uses a heated isokinetic probe and sample line, and a heated optical cell where the light scattering measurement is made. This approach allows the system to handle droplets. A sampling rake can be used if single point sampling is not satisfactory. Later instruments developed by Sick and Durag make direct in-situ measurements, although for wet systems they can be configured like the Sigrist system. In 1986 continuous PM monitoring was required at PM levels too low for opacity monitors. Light scattering is orders of magnitude more sensitive, however, and has become the method of choice for measuring low PM levels in Germany. Since 1986 TUV has approved 70 to 100 Sigrist systems, 200 to 300 Sick systems, and an unknown number of Durag systems.

Although a considerable amount of experience and data exists in connection with the TUV certifications and subsequent operations at various installations, this information is generally not available. TUV certifications are paid for by the CEMS manufacturer and are proprietary. CEMS operating data at facilities belongs to the individual facilities, and is also not public information. Since this data also represents the plant's emissions history they are reluctant to release it. For these reasons, TUV itself has no prepared reports on the general subject of PM CEMS performance. The only specific information that has been gathered to date comes from the TUV certification report for the Sick RM200 at a secondary lead smelter that Sick Optic-
Electronic has made available to the EPA (discussed in the nest section).

The TUV certification process includes both laboratory and field testing. The laboratory portion of the testing is carried out to determine if various performance specifications are met during the basic operation of the instrument. The field portion of the testing is termed "suitability" testing, and is carried out to determine the performance of the CEMS in actual operational conditions. Some aspects of the performance specifications that are evaluated during the laboratory testing include the following.

1) Sensitivity of the instrument output to temperature in the range of -20 to 50 C should be less than 2% of full scale.

2) Sensitivity of the instrument output to supply voltage fluctuations of -15 to +10% should be less than 2% of full scale.

3) Response of the instrument to a set of internal calibration standards (ie, neutral density filters) should be within < 2% of the standard.

Items 1) and 2) are requirements that the instrument output not be biased by two specific environmental variables: ambient (outside) temperature and supply voltage. Item 3) is essentially a linearity check, and ensures that to within 4% all like instruments give the same response. It is important to note that this means that each instrument of a particular model and make is required to have the same response. That is, the instruments are interchangeable. Thus, if an instrument that is installed and calibrated in the field fails or suffers from a deterioration of performance, a replacement instrument can be installed and identical readings obtained without the need to recalibrate.

Suitability testing is carried out to assess whether or not performance specifications for reproducibility, drift, and accuracy can be met under actual field conditions, and to assess the long term endurance and maintenance requirements of the CEMS. Some of the performance specifications are:

1) Zero point drift of < 2% over the maintenance interval.

2) Sensitivity drift, as determined by an internal calibration, of < 2% over the maintenance interval.

3) Automatic corrections to the reference point to account for the build-up of dirt on the optics are limited to 6%. At that point an alarm must be given and the instrument serviced. The time that it takes to reach this situation determines the maintenance interval, and is a function of the effectiveness of the purge system.

4) Data availability during the suitability test must be greater than 95%.

Items 1) and 2) are analogous to the zero and calibration drift requirements required by the EPA in the performance specifications set forth in 40 CFR part 60, appendix B. Items 3) and 4) are analogous to the data quality assurance requirements for zero and calibration drift and data availability set forth in 40 CFR part 60, appendix F.

In general, satisfactory performance must be demonstrated at each kind of facility for which the CEMS maker wishes to provide instruments by carrying out a suitability test. During the suitability test 2 to 3 calibrations are made over the duration of the test, which lasts from 3 to 6 months (there should be a 3 month separation between calibrations). A statistical correlation between the CEMS measurement and the PM loading must be demonstrated. The regulations also require that scale and zero checks be performed at least once per maintenance interval, although they may be performed more frequently. The maintenance interval is determined by TUV during suitability testing, and should be at least one week.

A hierarchy of difficulty in terms of suitability testing exists: incinerators are most difficult, followed by coal, oil, and gas fired plants. Thus, if suitability is established for incinerators, the instrument is also approved for the other type of facilities. However, if suitability is established, for example, for an oil fired facility, then the instrument is approved for oil and gas fired facilities only, not for coal fired facilities or incinerators.

At each site that a monitor is installed, a calibration against the manual reference method must be performed. This calibration is checked every 3 to 5 years. The calibration is used to establish a linear correlation between the instrument response and the PM mass loading. The calibration relation is only considered valid for the range of PM loadings over which the calibration is performed, thus it is preferred to calibrate over a PM range spanning approximately one-half to two times the emission standard. Natural plant variability may provide sufficient variation in PM loading to obtain a calibration, however, if this is not the case, then higher emissions can be obtained by, for example, replacing a bag with a plate with a hole in it. A calibration is performed by making simultaneous manual measurements. 15 to 20 measurements are made (a minimum of nine is required) in a network that provides spatial coverage of the duct. Typically half-hour samples are obtained, and for comparison the CEMS measurements are integrated over the manual method sampling period. TUV performs the calibrations, which have been carried out for dust loadings as low as 50 $\mu g/m^3$ (0.00002 gr/dscf). The costs for a calibration range from about $7,000 for a small stack to about $18,000 for a large one.

Because PM CEMS based on light scattering are sensitive to changes in particle size distribution and composition, the stability of the calibration is of concern. It has generally been found that for plants with a high degree of flue gas clean-up, for example hazardous and municipal waste incinerators, which must meet or exceed 0.005 gr/dscf, that a stable calibration can be obtained. However, if changes are made to the plant, or to its operation (such as different fuel type), then the CEMS must be recalibrated. If a facility expects to burn different types of fuels at different times, it can calibrate for each fuel and use the appropriate calibration as required. At the periodic recalibration that is required, four comparison measurements with the reference method are made initially. If they fall within the error bounds of the original calibration then a recalibration is not needed. As an example, Mr. Buhne mentioned a calibration check performed after 5 years. The measurements were 15% different, but within the error of the original calibration, so the original calibration was considered to still be valid.

The regulations pertaining to the use of PM CEMS for compliance monitoring in Germany are summarized below. Continuous monitoring of PM emissions are required for hazardous and municipal waste incinerators, and all boilers with a thermal capacity greater than 5 MW. Emission limits are specified for never to exceed, half-hour averages, and daily averages. The daily average emission limit for MWC's is 10 mg/m^3 (about 0.005 gr/dscf) and for HWI's it is 1 mg/m^3.

Instrument availability is required to be >90%. It is further required that there be at least 20 minutes of valid measurements per half-hour averaging period. Once per day, all the results are transmitted by phone to the government. Any alarms (exceedances) are transmitted immediately. The measurement range of the instrument should be from 10% of the emission limit to 2.5 times the emission limit (full scale). Upon installation, the CEMS must be calibrated against manual gravimetric measurements. Periodic recalibration is required at 3 to 5 year intervals depending on the type of facility. The uncertainty of the calibration relation, taken at the emission limit, gives the maximum measured value that is allowed (emission limit plus uncertainty). This value is determined for daily and hourly averages as well as for single data points. There is a required yearly linearity check, which is performed by TUV or an equivalent organization using calibrated filters . The German regulations pertaining to CEMS are compared to the EPA requirements as contained in 40 CFR part 60, appendices B and F in Table A-4.

The German approach to the use of CEMS for compliance monitoring is based on the application of a practical engineering philosophy. CEMS are employed, despite the known sensitivities to various factors such as particle composition and size distribution, within the statistical limitations determined by a site specific calibration procedure that defines the statistical relationship between CEMS response and PM loading. The reliability of the CEMS and the statistical relationships are assured as best as possible through performance based CEMS specifications and suitability testing and other long term tests run on plants at normal operating conditions using both CEMS and manual methods. This allows the development of confidence in the utility of the CEMS.

The calibration of PM CEMS over a range of plant and APCD operating conditions allows a fit to a range of data that covers differing PM properties and size distributions. The resulting correlation will have larger uncertainty than one derived from changes to PM loading alone, but this is known and taken into account by the statistical treatment of the data. This is illustrated in Figures A-1 and A-2, which follow an example from Jahnke (1984). Figure A-1 shows three hypothetical calibrations obtained for three different combinations of particle properties and size. For each individual type of particle, the calibration is obtained by varying loading only. The correlation (dashed line) for each calibration is very good. In practice, a calibration obtained by varying plant parameters might result in a set of data encompassing all of the points in Figure A-1. The calibration that would be derived is shown in Figure A-2 (dashed line), from which it can be seen that a much larger statistical uncertainty (bounded by the solid lines) is associated with the regression analysis. However, given this uncertainty, the relationship is still useful, and compliance can be based upon it.

A.1.13 <u>Example of TUV Certification</u>

The only documentation that EPA was able to obtain was provided by Sick Electro-Optic and described the TUV certification of the Sick RM200 light scattering based PM CEMS at a secondary lead smelter (TUV Rheinland, 1992). The laboratory phase of the testing was carried out using the RM100 soot number detector, which is identical to the RM200 except for the available measurement ranges. Tests of sensitivity to changes in temperature and voltage, and response to standard calibration aids were passed satisfactorily

Duration, or suitability testing, was carried out downstream of the baghouse at a secondary lead smelter. Three RM200 units were installed in January of 1991 on a horizontal section of an 1 m diameter duct. The units were calibrated against duplicate reference method measurements on 4/15 & 16 of 1991. In the interim, the linearity of the units was checked (the units passed as the results were within 2% of the standards). During the January to April time period problems with the operation of one of the units were encountered due to a loose screw, and the same unit also exhibited some sort of temperature sensitivity (which was never fully diagnosed and which eventually went away, but which should not have occurred at all). During the calibration, drift was observed due to temperature sensitivity and stray sunlight. In April and May dirt build-up on the optics due to problems with the purge system caused periodic episodes of continuous initiation of calibration cycles. There was also an instance of simultaneous initiation of calibration cycles by all three units due to voltage fluctuations.

A second calibration was carried out on 5/27 of 1991 and the units were inspected. It was found that the light traps were badly corroded, and one was filled with deposits. The optics on at least one of the units were found to be very dirty due to a faulty purge system. Subsequent repairs and minor changes to the purge system were not effective in keeping the optics clean. The operational consequence of dirty optics is that the instrument carries out frequent calibration cycles to correct for the problem. However, dirt accumulation leading to over 6% attenuation is considered to be automatically out of specification. On 6/7 a modified purge system was installed, but by 6/20 unit #3 was dirty again. A check of all the instruments made on 6/25 showed the following attenuations due to dirt build-up on the optics of each instrument: #1 3.4%, #2 7.5%, #3 14%. The units were cleaned, but by 6/28 #1 and #2 were heavily dirtied again and running repeated calibration cycles. By 7/1 unit #3 was dirty also. At this point TUV and Sick agreed to halt the testing and Sick started work on a redesign of the instrument, particularly the purge system.

On 9/6 testing was resumed with two new instruments, #4 and #5. By 9/16 #4 had evidence of dirt build-up, and as a result a part was changed. From 9/30 to 11/2 both units ran with no problems: there was some dirt build-up, but it was largely within limits and the systems produced valid measurements. A history of the attenuation checks is as follows: 10/2 - #4 6.1% (cleaned), #5 1.7%; 10/25 - #4 2.2%, #5 3.9%; 11/4 - #5 5.2%; 11/8 - #4 2.2%, #5 6.4%. On 9/30 and 10/2 units 4 and 5 were calibrated.

The results of the duration testing are summarized below.

a) Reproducibility: Units 1,2, and 3 from 3/13 - 6/5 FAILED. Units 4 and 5 from 9/6 to 11/8 PASSED.

b) Availability: (should be >95%). All units passed.

c) Calibrations: the measurement network used for the manual reference measurements confirmed the representativeness of the CEMS measurement points. The duplicate RM200 measurements were better at the end of the test period (new units #4 and #5) due to better rejection of stray light. A statistical correlation between the RM200 measurements and total PM was demonstrated. The correlation coefficient for data lumped together from all three calibrations was 0.891. The individual calibrations were found to have a relatively large uncertainty which was ascribed to the working of the kiln, which operates in cycles: charging, smelting, removal, slag melting and removal (which presumably gives rise to highly variable particulate properties). No attempt was made to assess the stability of the calibration using the data from the three calibrations.

The uncertainty in the calibration data described above is presumably worse than what might be seen at other types of plants for the reason given above (the uncertainty in the calibration cannot be explained as that due to the reference method, although the reference method does have higher uncertainty than the RM200 measurements). In the TUV analysis, all the calibrations are used together to demonstrate the existence of an acceptable correlation between the RM200 measurements and PM loading. It is stated that, in principle, this data can be used to show the stability of the calibration, but this was not done. The data from the three calibrations covers data from times when the instruments were having some difficulty due to the rapid build-up of dirt on the optics. The design of units 4 and 5 was also apparently changed to allow better rejection of background light. However, the use of all the data by TUV to make a master calibration seems to indicate that the data is, to at least some degree, directly comparable; therefore a comparison of the initial calibration to data taken during the later calibrations is carried out here. The data from the first calibration, along with the regression line and confidence and tolerance intervals are shown in Figure A-3. Figure A-4 shows the same regression analysis with data from the second and third calibrations overlaid. Within the rather large statistical uncertainty of the regression analysis of the first calibration, all of the data are consistent. There do appear to be some systematic variations in the data in that almost all of the second and third calibration series data lies below the regression line itself, but almost all of the data are within the tolerance interval of the first calibration. The master calibration based on all of the calibration data is shown in Figure A-5 along with confidence and tolerance intervals. The data points and regression line from this graph are shown again in Figure A-6 in relation to the regression line, confidence interval, and tolerance interval of the initial calibration. Note that, although the master calibration regression analysis can be taken as the "true" relation between RM200 response and PM loading for this facility, within the confidence interval calculated from the first calibration series, the regression line for calibration series one is in agreement with the master calibration. One can conclude, then, that within the statistical uncertainty of the data, the calibration relation for the RM200 response and the PM loading remained constant over the duration of the suitability testing, a period of about 6 months.

The duplicate reference method measurements are shown in Figure A-7 for the third calibration series, and the duplicate RM200 measurements are shown in Figure A-8. The reproducibility of the RM200 measurements is excellent, and is considerably better than that for the reference measurements. For units 4 and 5, TUV determined that the reproducibility, defined as R = <X>/U, where <X> is the mean of the measurements from the two instruments and U is the uncertainty, was greater than 30, as required (this corresponds to a fractional error between duplicate measurements of 3.3% or less).

It should be noted that TUV approval testing is part of any development program for a CEMS in Germany and is used as a final test to verify that the performance objectives have been met. The Sick RM200 was the first instrument using an in-situ approach for light scattering monitors and the problems revealed during the suitability testing of instruments 1, 2, and 3 reflect this fact. Furthermore, these problems were related to the suitability of the design of the instrument for in-situ monitoring rather than to any fundamental questions concerning the stability of the calibration relation, which is a separate issue. Based on the results of the endurance testing described above, in particular the performance of the new units 4 and 5, the RM200 received TUV approval with a 4 week maintenance (optical cleaning) interval required.

The description of the TUV certification of the Sick RM200 at a secondary lead smelter illustrates the PM CEMS approval process. The initial performance of the device was unsatisfactory. However, the maker redesigned the instrument and testing was continued. The redesigned device passed the performance requirements and gained approval, with TUV specifying the maintenance interval based on the test results. The data from the certification test also demonstrated a good correlation between the RM200 response and PM loading. Analysis of the data shows that the calibration of the RM200 remained stable, within the statistical confidence interval of the linear regression to the data, over the 6 month duration of the testing.

A.1.14 Conclusions

A variety of devices capable of continuously monitoring PM emissions are currently commercially available. Of the approaches surveyed in this report, one is not suitable for stack monitoring (the TOEM), and opacity monitoring lacks the required sensitivity. Of the remaining approaches, none makes a direct measurement of particle mass concentration, although the beta gauge calibration depends so weakly on particulate properties that the calibration is considered universal and absolute (Wedding and Weigand, 1993). The other devices require a site specific calibration against manual gravimetric measurements. The accuracy that can be obtained in this manner is not known, as it depends on the stability of the calibration. This depends in turn on a stable relationship between the measured particle properties and particle mass. The best way to determine the feasibility of applying these devices as CEMS for compliance purposes is to conduct field trials at the various types of sources to be regulated. A demonstration of these devices at facilities representative of the various source categories should determine how actual variations in PM size and composition affect the accuracy of mass concentrations inferred from the measured properties. It should be noted that in Germany, light scattering has been deemed sufficiently reliable for this method to have received certification for use as a CEMS.

A.2 CEMS FOR MERCURY

A.2.1 Introduction

There are two classes of CEMS for mercury: those designed to measure total mercury emissions (elemental and speciated mercury) and those that measure gas-phase elemental mercury only. The latter are designed to make direct in-situ measurements using optical techniques. The former include CEMS based on a variety of different approaches, some of which can also measure PM bound mercury. All of these CEMS are extractive. The approaches taken to making total mercury measurements employ thermal, catalytic, or chemical processes to convert speciated mercury to elemental mercury followed by detection of elemental mercury by means of photometric techniques or solid state sensors. One approach does not use a converter but instead attempts to measure the different mercury species directly. Mercury CEMS, organized by these different types of technologies, are listed in Table A-5. The CEMS makers and developers listed in this table comprise all of the potential CEMS that have been identified in this study. There may be developers pursuing other approaches or the same approaches identified here that were not contacted and listed in the table.

A.2.2 Verewa Total Mercury Monitor

The Verewa total mercury monitor uses a heated probe to isokinetically extract a continuous sample of stack gas. The sample then passes through several treatments before being analyzed. The first treatment uses an IR oven to heat the sample to 800C, which vaporizes Hg on PM and destroys all organic compounds, which can cause interferences. The second treatment uses a sodium-hydroboron solution to reduce all mercury compounds to elemental Hg. Elemental mercury is then detected in the gas phase by a UV photometer. Calibration is achieved by introduction of a mercury solution upstream of the IR oven. The detection limit of the device is specified as less than 10 µg/m^3. The maintenance interval of the device is cited as being greater than one week, and the solutions used in the device need periodic replacing. The Verewa total mercury monitor is currently commercially available in the US and costs $130,000, although it has not been demonstrated in the US. It has TUV lab approval, and is currently undergoing field trials in Germany. About fifteen units are installed worldwide (Verewa, 1994).

Advantages:

- Only monitor commercially available for total Hg.
- Measures total Hg: elemental, speciated, and PM bound.

Disadvantages:

- Relatively complex flow system for chemical conversion of speciated mercury.
- Solutions need replenishment.

A.2.3 ADA Technologies Total Mercury Monitor

ADA Technologies is developing a total mercury monitor that will be capable of measuring both total mercury and elemental mercury concentrations. By taking the difference between these two measurements, the speciated mercury concentration can also be reported. The monitor makes these measurements by employing a thermal converter (which can be bypassed) and a patented UV absorption cell for detection of elemental mercury. The converter is designed to convert all speciated mercury to elemental mercury, and has been tested in the laboratory with mercuric chloride and methyl-mercury. The stack gases are sampled continuously and first passed through a particulate filter, so as currently designed the monitor does not measure PM bound mercury. Calibration is accomplished using two calibration sources: a permeation tube for elemental mercury which is used to calibrate the detector, and a diffusion vial for mercuric chloride, which is used to calibrate the converter. Detection limits for this device are specified as being less than 1 µg/m^3.

ADA currently has assembled and tested their first prototype instrument. It has been field tested at a plasma hearth waste treatment unit operated by SAIC in Idaho Falls, ID. Details of and data from this testing are not available. ADA plans to have a commercial instrument by the end of

1995 produced in partnership with Land Combustion (Schlager et al., 1995 and ADA technologies Inc., 1995).

Advantages:

- < 1 $\mu g/m^3$ detection limit.
- Simple conversion of speciated to elemental mercury.
- Capability to report split between elemental and speciated mercury.
- Calibrates with both elemental mercury and mercuric chloride sources.

Disadvantages:

- Does not measure PM bound mercury.
- Not commercially available or extensively field tested.

A.2.4 Senova Total Mercury Monitor

Senova is developing a total mercury monitor that uses a catalytic converter to convert speciated mercury to elemental mercury and a solid state sensor to detect elemental mercury. No information is available on the performance of the converter, and calibration is accomplished with an elemental mercury permeation tube only. The detection limit of the monitor is specified as less than 1 $\mu g/m^3$. The stack gases are sampled continuously and first passed through a particulate filter, so as currently designed the monitor does not measure PM bound mercury.

A prototype of this monitor will be tested as part of the joint DOE/EPA CEMS demonstration to be conducted at the IRF in Jefferson, Arkansas in July through September of 1995. Senova expects to have a commercial instrument ready sometime in 1996. They currently have a phase II SBIR in place to develop a capability to measure PM bound mercury as well (Senova Corp., 1995).

Advantages:

- < 1 $\mu g/m^3$ detection limit.
- Simple conversion of speciated to elemental mercury.

Disadvantages:

- Does not measure PM bound mercury.
- Not commercially available or extensively field tested.

A.2.5 PSI Total Mercury Monitor

Physical Sciences Inc. (PSI) is developing a total mercury monitor based on dielectric barrier discharge technology and emission Spectroscopy for detection. This monitor uses dilution sampling to extract a continuous sample from the stack. The sampled gas then enters a dielectric barrier discharge. The discharge excites nitrogen (the predominant background gas), which in turn excites elemental mercury. The nitrogen also dissociates $HgCl_2$ to HgCl, which also emits light. A spectrometer can then be used to detect the emission from elemental mercury and HgCl at their respective characteristic wavelengths. To date, laboratory tests have demonstrated quantitative detection of elemental mercury and mercuric chloride ($HgCl_2$). Detection of PM bound mercury has also been demonstrated, but not on a quantitative basis. Detection of other speciated mercury compounds has not been demonstrated, and may be problematic, as each species must be spectroscopically detected on an individual basis in this approach. Detection limits for this monitor are estimated to be in less than 10 $\mu g/m^3$. Calibration is performed with mercury permeation tubes and mercuric chloride diffusion vials.

PSI currently has a prototype that they plan to begin field testing in the fall of 1995 under a phase II SBIR. They do not yet have an estimated time to market for this device, and it may not be suitable as a total mercury monitor (it may be marketed as an elemental mercury monitor only) (Physical Sciences Inc., 1995).

Advantages:

- May measure PM bound mercury.
- Makes direct measurement of elemental mercury and mercuric chloride (does not rely on a converter.

Disadvantages:

- May not measure all forms of speciated mercury.
- Not commercially available or extensively field tested.

A.2.6 ABB Opsis Elemental Mercury Monitor

The Opsis system makes in-situ (cross-stack) measurements using the optical measurement technique known as differential optical absorption Spectroscopy (DOAS). The principle is as follows. Many species absorb infrared, visible, and ultraviolet light. A broadband light source is projected through the gas sample to a detector, and species present in the sample absorb light from the beam at characteristic wavelengths. The measurement is made by using a spectrometer to look at both the specific spectral bands where absorption occurs and at reference wavelengths where no absorption occurs. The difference in the transmitted light at these wavelengths can be used to calculate concentration.

The Opsis system is a multicomponent analyzer. It can simultaneously detect some acid gases, NO_x, SO_x, water, and many organics (it operates at both IR and UV wavelengths), as well as elemental gas phase mercury. Different configurations can be purchased which will detect different combinations of these pollutants, including one version that measures mercury only. However, the single component system for mercury costs $120,000, while the multicomponent system only costs $150,000. Detection limits depend on the measurement path length: for a 5 meter path, the detection limit for elemental mercury is 2 $\mu g/m^3$ (10 $\mu g/m^3$ for a one meter path). Opsis is TUV approved in Germany, and there are over 100 units of all types installed worldwide. Opsis provides continuous measurement, and maintenance is low: about two hours per month, with three to four days of initial training (ABB Power Plant Controls, 1995 and TUV Rheinland, 1995).

Advantages:

- Multicomponent measurements.
- In-situ.
- Commercially available and TUV certified.

Disadvantages:

- Elemental mercury only.

A.2.7 Summary

The various total mercury monitors under development differ in whether or not PM bound mercury is detected, whether or not the converter is bypassed to give a separate measurement of total and elemental mercury, and in details of calibration. However, all of these monitors could be easily modified to allow measurement of PM bound mercury by addition of an oven, to allow separate measurement of total and elemental mercury by addition of a bypass around the converter, and to calibrate with both elemental mercury and mercuric chloride by the addition of another calibration source. Thus several technologies for the measurement of total mercury appear to be feasible and will be available soon. The PSI mercury CEMS is probably the furtherest from market, and may be applicable to elemental, or to elemental plus mercuric chloride only. It may thus find application only in certain situations. The Opsis system, while offering simplicity, and multi-component in-situ measurement capability, only measures elemental mercury. For mercury monitoring, it also may find application in only certain situations, such as downstream of wet scrubbers providing control of mercuric chloride.

A.2.8 Conclusion

A variety of mercury monitors are already available or under development with availability scheduled within the year. Three of these monitors will most likely be suitable for monitoring total mercury: elemental gas phase and PM bound mercury, and speciated mercury. In addition, at least one and possibly two monitors will be available for measuring elemental mercury only. All of these monitors will have detection limits below or substantially below the proposed mercury emission limit. Two of these monitors will have undergone testing by TUV in Germany. However, at this point little field testing has taken place in the US. A demonstration program with field testing of the CEMS against EPA reference methods will be required in this country in order to ensure the successful application of these monitors to emission monitoring for compliance on hazardous waste burning facilities.

A.3 CEMS FOR ACID GASES

A.3.1 Introduction

There is a broad range of different approaches to making measurements of acid gases (mainly HCl and Cl2). These include non-dispersive infrared (NDIR) Spectroscopy, ion-selective electrode (ISE) techniques, ion mobility Spectroscopy (IMS), ultraviolet (UV) Spectroscopy, colormetric techniques, Fourier Transform infrared (FTIR) Spectroscopy, and mass spectrometric techniques. Acid gas CEMS, organized by these different types of technologies, are listed in Table A-6. Note that not all makers of CEMS of a given type were contacted (although in each case at least one was, in order to establish the capabilities and approximate cost of the technology), and that not all makers in each category are necessarily listed. The colormetric CEMS is not included in the discussion that follows because field tests have shown that it is not an appropriate technology for monitoring stack emission of HCl from hazardous waste incinerators (Shanklin et al., 1991).

A.3.2 NDIR Spectroscopy

The term "non-dispersive infrared (NDIR) Spectroscopy" actually covers a variety spectroscopic techniques. However, the four NDIR based HCl CEMS identified here utilize the same approach, which is known as gas filter correlation (GFC). The GFC technique involves making a sequential measurement. First, a broadband infrared (IR) beam is passed through the gas sample to be analyzed. All species present in the gas sample that can absorb the IR beam do so, including the target species, in this case HCl. Second, a gas filter containing the target species is also placed in the beam. This removes light absorbed by only that species from the beam. The light then passes through the gas sample, where, as before, all species absorb some of the light. Thus the difference in the amount of light reaching the detector in these two cases is due solely to absorption by the target species. This technique is thus a powerful way to eliminate spectral interferences, and can be applied to making measurements of many different species.

Four CEMS for monitoring HCl using the GFC technique are commercially available. These are made by Bodenseewerk, TECO, Servomex, and AIM. Bodenseewerk and AIM also make multicomponent GFC analyzers for NO_x, SO_x, CO, CO_2, H_2O, CH_4, NH_3, and HCl. Bodenseewerk, Servomex, and AIM use hot/wet extractive sampling systems, while TECO uses a dilution sampler. As discussed in Section A.4.9, a GFC based analyzer using hot/wet sampling has been shown to operate successfully on HWI's. AIM also makes versions of their CEMS employing cross-stack in-situ monitoring. Costs for the various systems are summarized in Table A-6, and performance in Table A-7. These types of systems typically have detection limits around 1 ppm, response times of under a minute, and are interference free. All four makers have numerous systems installed world-wide, Bodenseewerk is TUV approved in Germany, and Servomex has passed certification testing in the State of Maryland (Shanklin et al., 1991, Thermo Environmental Instruments Inc., 1994, Servomex Co., 1994, Air Instruments and Measurements Inc., 1994, and Joseph et al., 1993).

Advantages:

- Sensitivity to 1 ppm and below (longer path length cells can be used, which increase cost and response time).
- Interference free.
- Relatively inexpensive.
- Can be combined with a multi-component analyzer.

Disadvantages:

- Does not measure Cl_2.

A.3.3 Ion Selective Electrode

The ion selective electrode (ISE) approach is based on a potentiometric measurement using a Cl^- ion-selective electrode. Typically a hot/wet extractive sampling system is used to bring the stack gases into contact with a scrubbing solution. The solution is formulated to adsorb HCl from the gas phase and to ensure dissociation to produce Cl^- ions for detection. Early ISE HCl CEMS had interference problems from other halides present in the stack gases from HWI's (see Section A.4.9), however, at least two of the makers (Tess-Comm and Bran & Luebbe) have reformulated their solutions to avoid these problems. Bran & Luebbe has 500 to 600 systems installed on stacks world-wide, with about 30% of those being HWI's. The Bran & Luebbe is TUV approved in Germany.

The ISE approach is characterized by very low detection limits: Bran & Luebbe cites 0.3 - 0.4 ppm and Tess-Comm 0.4 ppb. Routine calibration can be accomplished using NIST traceable liquid solutions, and the devices are equipped to allow a gas calibration for relative accuracy tests. Response times of the instruments are less than one minute. ISE HCl CEMS are not sensitive to Cl_2. HF can also be detected using this technique, but a separate analyzer is required (Tess-Comm Inc., 1994 and Bran and Luebbe Inc., 1994).

Advantages:

- Excellent sensitivity: sub ppm.
- Relatively inexpensive.

Disadvantages:

- Does not measure Cl_2.
- Requires replenishment of scrubber solution.

A.3.4 Ion Mobility Spectroscopy

IMS systems are made for a wide variety of compounds and groups of compounds. In general, a separate analyzer is required in each case. Specificity is achieved in an IMS system through several different processes. First, a dilution sampling system is used to present a sample of stack gas to one side of a semi-permeable membrane. The membrane allows the species of interest to pass into the sample cell while rejecting or attenuating possible interferants. Next, the sample is ionized by a weak plasma generated by beta radiation from a radioactive source. A dopant may be added at this stage to increase ionization of the target species and thus further enhance specificity.

The ionized sample is allowed periodically to enter a drift tube where the ions are propelled toward a detector by an electric field. As they cross the drift tube they are separated on the basis of charge, mass, and shape. The time-dependent current generated by the detector constitutes a spectrum which is analyzed by a microprocessor to determine concentration based on peak height.

ETG makes IMS systems for HCl and Cl_2, HF and F_2, HBr and Br_2, I_2, and Cl_2O. Note that the HCl monitor is sensitive to Cl_2 as an interferant. The use of two analyzers with different ratios of HCl to Cl2 sensitivities could in principle be used to measure determine both HCl and Cl2 concentrations. This approach has never been attempted or demonstrated, however. The ETG IMS CEMS have sub-ppm sensitivity to HCl and HF with response times on the order of 30 seconds. ETG HCl IMS CEMS are installed on some stacks, mostly outside of the US (Bacon and Reategui, 1993 and Environmental Technologies Group, Inc., 1994).

Advantages:

- Excellent sensitivity: sub ppm.
- Measures total chlorine in both HCl and Cl_2.
- Relatively inexpensive.

Disadvantages:

- Can not distinguish between HCl and Cl_2.

A.3.5 Differential Optical Absorption Spectroscopy (DOAS)

The DOAS technique described previously in Section 3.2.6 for mercury monitors can also be applied to the measurement of Cl_2 using ultraviolet light and HCl using infrared light. ABB makes a system called Opsis based on this approach that is a multicomponent analyzer. It can simultaneously detect HCl and Cl_2, Cl_2O, and HF (as well as Hg, NO_x, SO_x, water, and many organics). Opsis is designed for open path measurements and for cross stack monitoring. Detection limits depend on the measurement path length: for a 20 foot path, the detection limit for Cl_2 is about 4 ppm, and for HCl it is sub-ppm. Opsis is TUV approved in Germany (ABB Power Plant Controls, 1995).

Advantages:

- Good sensitivity to HCl, Cl_2, and HF.
- Multicomponent measurements.

- In-situ.

Disadvantages:

- Relatively expensive.

A.3.6 FTIR

Fourier transform infrared (FTIR) Spectroscopy is an alternative technology to NDIR for measuring species concentrations based on infrared absorption that is capable of making simultaneous multiple species measurements. FTIR uses a broadband IR light source that is passed through the sample gas. The light then passes through a scanning Michelson interferometer, which rapidly samples a wide region of the IR spectrum. The resultant interferogram is recorded as the time dependent signal from a detector. A spectrum is recovered by Fourier transforming the detector output. The spectrum is then compared to reference spectra to identify species and make quantitative concentration measurements. The Fourier transform and comparison processes require a computer and sophisticated software.

FTIR spectrometers are available from quite a large number of makers for both open path measurements and for stack sampling. Stack sampling configurations use extractive probes and multipass absorption cells. For HCl, the sampling system and cell must be heated. Several FTIR makers provide such systems. These systems are typically capable of measuring CO, NO_x, SO_x, H_2O, NH_3, CH_4, HCl, HF, and HBr down to the 1 ppm level. Water vapor and CO_2 can both pose problems as interferants. Background from these two species can be handled by subtracting the appropriate reference spectra, and, in the case of water, by attempting to dry the sample. However, the presence of this background is often the limiting factor in making FTIR measurements.

FTIR CEMS are in routine use at a variety of different types of facilities for CO, CO_2, NO_x, SO_x, and VOC monitoring. FTIR systems for making HCl measurements are installed at a number of sites as demonstration systems (KVB, 1994, Enviroplan, 1994, Vidrine and McIntosh, 1993, Plummer et al., 1993).

Advantages:

- Good sensitivity: to the ppm level.
- Multicomponent analysis
- Can measure HF and HBr in addition to HCl.

Disadvantages:

- Can not measure Cl_2.
- Moderately expensive
- Ability to correct for water vapor interference is limiting factor for performance

A.3.7 Mass Spectrometry

Mass spectrometers operate by ionizing a gas sample in a vacuum chamber (by any one of several techniques, each with its own advantages). The species present in the gas are both ionized and fragmented. The ions then pass through a mass filter that separates them based on mass-to-charge ratio. The mass-to-charge ratio that is passed by the mass filter is continuously varied, thus generating a mass spectrum. Each species generates a distinctive spectrum, and can thus be identified and quantitated.

Many companies market process mass-spectrometers, which are capable of detecting any and all of the acid gas species of interest as well as many other components. Mass spectrometers integrated with hot/wet sampling systems for acid gas measurement are not commercially available, however, a prototype system has been tested with satisfactory results (Bartman et al., 1994). Mass spectrometers are in general capable of sub-ppm sensitivity.

Advantages:

- Excellent sensitivity: sub-ppm.
- Multicomponent analysis
- Can measure all acid gases in addition to HCl.

Disadvantages:

- Expensive

A.3.8 Summary

The main characteristics of each type of acid gas CEMS are summarized in Table A-7. NDIR, ISE, and IMS are marketed commercially for HCl monitoring, and many units are already installed worldwide. The UV system also has the capability to monitor HCl and Cl_2, although it is sold as a multicomponent monitor. Units are currently installed worldwide, some of which are monitoring HCl. FTIR is also a multicomponent CEMS with the ability to monitor HCl, however, only a few systems are installed on a demonstration basis. And finally, MS, also a multicomponent technique, is still in the demonstration phase.

A.3.9 Previous Field Studies

From 1986 through 1991 the Quality Assurance Division of EPA's AREAL contracted with Entropy Environmentalists, Inc., to carry out a series of field tests evaluating HCl CEMS. Test were carried out at three municipal waste combustors (MWC's) and at two hazardous waste incinerators (HWI's) (Shanklin et al., 1991, Shanklin et al., 1989, and Rollins et al., 1988). The testing at the HWI's revealed problems with the CEMS that were not found during testing at the MWC's. A second round of testing at a HWI was carried out in 1990 after the CEMS makers had a chance to correct the shortcomings of the devices. A summary of the testing and the results follows below.

Initial tests were performed at MWC's with the following CEMS:

1) TECO Model 15 (NDIR gas filter correlation device with dilution probe).
2) Bodenseewerk Spectran (NDIR gas filter correlation device with heated sampling system).
3) Bran & Luebbe Ecometer (ISE with heated sampling system).
4) MDA Scientific Series 7100 (Colormetric, no sampling system).

The MDA colormetric system did not respond to HCl in the effluent sample, although it did respond to calibration gases. This system was dropped from further testing. At MWC's that did not control HCl emissions, the other three CEMS operated successfully. Test at MWC's that did control HCl emissions were inconclusive because the emission levels were very low (1 - 10 ppm), which made relative accuracy difficult to assess (there was also some concern over the accuracy of the calibration standard at these levels).

The first round of testing at an HWI in 1989 was conducted at the Trade Waste Incineration (TWI) facility in Sauget, IL. The CEMS tested were:

1) TECO Model 15 (NDIR gas filter correlation device with dilution probe).
2) Bodenseewerk Spectran (NDIR gas filter correlation device with heated sampling system).
3) Bran & Luebbe Ecometer (ISE with heated sampling system).

The results from the tests were inconclusive because: 1) the TECO dilution probe plugged; 2) the Bran & Luebbe electrode was fouled by a reaction with iodide; and 3) the Bodenseewerk Spectran was not set-up properly for the stack gas H_2O levels that were encountered. A second round of testing in 1990 was also conducted at the Trade Waste Incineration (TWI) facility in Sauget, IL after steps has been taken to correct each one of these problems. The CEMS tested were:

1) TECO Model 15 (NDIR gas filter correlation device with dilution probe).
2) Bodenseewerk Mekos 100 (NDIR gas filter correlation device with heated sampling system).
3) Bran & Luebbe Ecometer (ISE with heated sampling system).
4) Kyoto Model HL-26-11N (ISE with heated sampling system).
5) Tess-Comm Model 745 (ISE with heated sampling system).

The results of the performance evaluation were the following:

1) The ISE based CEMS were not reliable due to interference problems (the fix for the Bran & Luebbe CEMS was not successful).
2) The TECO system, which had earlier suffered from probe plugging problems, was operated successfully by heating the sampling system to a temperature 30F higher than the stack gas temperature. However, reliable operation was not achieved. It was thought that use of a dilution probe resulted in HCl levels at the analyzer that were too low to measure reproducibly.
3) The Bodenseewerk Mekos operated reliably.

A third round of testing was held in 1991 at a different HWI downstream of a wet scrubber. The CEMS tested were:

1) Tess-Comm (to asses whether they had fixed the interference problem).
2) TECO Model 15 (with a Perma-Pure drier in the sampling system rather than using a dilution system).

The results were the following:

1) The Tess-Comm operated successfully. The interference problem appears to be fixed.
2) The sampling system for the TECO system did not perform adequately.

In summary, one ion selective electrode system (Tess-Comm) and one NDIR system (Bodenseewerk) were shown to operate successfully at a hazardous waste incinerator. The TECO system, which does not utilize heated components, was unable to handle conditions characterized by less than 100 ppm HCl and greater than 20% H2O. The other ion selective electrode systems tested did not operate successfully at the HWI, although they may have been improved since the 1990 test, as the Tess-Comm was.

A.3.10 Conclusions

A large number of CEMS for HCl monitoring, encompassing a variety of different technologies, are currently commercially available. These include devices based on NDIR, ISE, IMS, and UV Spectroscopy. In addition, CEMS based on FTIR are available, although not in widespread use. Finally, the adaption of process mass spectrometers to HCl CEMS application has been demonstrated. Of these system types, NDIR and ISE have been evaluated at a HWI by the EPA (in 1990 - 91), and satisfactory performance was demonstrated. Since then systems based on IMS and UV Spectroscopy have become available and have been put into service. Systems based on NDIR, ISE, and UV Spectroscopy have been approved by TUV in Germany.

In conclusion, a variety of CEMS are available for immediate service monitoring compliance with HCl emission standards. Several of these CEMS are also capable of measuring other acid gases, either through the use of a second system (ISE, IMS), or simultaneously with a single instrument (DOAS, FTIR, MS). Cl_2 emissions can be monitored by UV DOAS or mass spectrometry (although this has not been demonstrated in the field).

A.4 CEMS FOR MULTI-METALS

A.4.1 Introduction

Current measurements of toxic metals are made using EPA Draft Method 29. Method 29 involves sampling the stack flow and collecting particle phase metals on a filter and volatile metals in a series of liquid filled impingers. The filters and impinger solutions are then sent to an analytical chemistry lab. The filter samples are digested in acid, and both the filter and impinger solutions are typically analyzed by inductively coupled plasma atomic emission Spectroscopy (ICP-AES). This procedure is capable of detecting all of the toxic metals of interest. In fact, the stack gas detection limits are determined by the volume of stack gas sampled. Since the sampling rate is chosen to ensure isokinetic sampling conditions, the sample volume is determined by the length of time that the stack gas is sampled. Typical samples are 1 to 5 m^3 and take several hours to collect. There are several limitations associated with Method 29. It is a manual technique for which continuous sampling is not practical. In addition, sending the samples to an analytical laboratory for analysis is time consuming and expensive. Thus Method 29 is not suitable for use as a CEMS, a purpose for which it was never intended.

The desired attributes of a metals CEMS are: continuous sampling of emissions, as close to real-time reporting as is practical, and automated, low-cost operation. In addition, detection limits must be low enough to assure compliance with regulatory limits. In this section five CEMS under development are described.. These CEMS (listed in Table A-8) are known as 3M (developed for use monitoring emissions from 3M's hazardous waste incinerator), HEST (Hazardous Element Sampling Train, under development by Chester Environmental), SPICAP (under development by Midwest Research Institute), on-line ICP (three different development efforts under way), and LASS (Laser Spark Spectroscopy, under development by Sandia-Livermore). The 3M CEMS is a semi-continuous method: sampling is continuous but averaged over long time periods, and analysis is on a batch basis using Method 29 techniques. The HEST CEMS collects a sample on filters which are analyzed by X-ray fluorescence (XRF) Spectroscopy. SPICAP collects the sample continuously in a liquid scrubber, and analysis is performed by standard ICP techniques. In the on-line ICP approach, the sampled stack gases are injected directly into an ICP for analysis. And finally, in LASS a laser is used to create a plasma directly in the stack gas, and the resultant atomic emission is used to analyze the metals concentrations. It should be noted that the analysis and discussion that follow are not based on a comprehensive literature search or industry survey. In fact, in certain cases, developers of CEMS technology are reluctant to make their efforts known or to release any detailed information.

A.4.2 3M

The 3M metals emission monitor is a "semi-continuous" technique that employs batch sampling to provide time averaged measurements (MRI, 1993). The sampling is performed at a single point and is subisokinetic (since particles at the 3M incinerator are primarily less than 2.5 microns). Particles are captured on a quartz filter and metals analysis is performed in the same manner as in Method 29. The volatile fraction is collected on a carbon impregnated filter (CIF) rather than the series of impingers used in Method 29. Once the volatile sample is digested, analysis is by the same methods as Method 29. The use of a CIF to capture volatile metals is a potential improvement over Method 29, as this eliminates the considerable complexity of using multiple impingers. 3M proposes to sample continuously, with the filters changed manually at fixed intervals (a sample interval of 4 hours was used in the preliminary tests described below) and sent to a laboratory for digestion and analysis. Thus the 3M method is a manual method with several simplifications over Method 29 to allow continuous sampling.

The 3M metals emissions monitor is being developed (by 3M, with assistance from MRI) to provide continuous sampling of the stack emissions from the 3M hazardous waste incinerator for compliance monitoring purposes. A preliminary validation test has been carried out in order to evaluate the essential features of the 3M method through comparison with Method 29. These features are:

- Single point sampling at a location in the fan breeching rather than high on the stack.
- The use of subisokinetic sampling in a situation where 80% of the particles are less than 2.5 microns.
- The use of carbon impregnated filters (CIFs) for volatile metals sampling.

The results of the preliminary tests are described below. They have importance ranging beyond the validation of the 3M approach in that they address several issues associated with features that the 3M method has in common with other proposed CEMS, such as single point probe sampling and the use of CIFs.

- Mercury concentrations measured through the use of CIFs were about 10 times those measured by standard Method 29 procedures. The reason for this discrepancy is unknown at this time.
- The use of single point sampling in the fan breeching was evaluated by carrying out a Method 301 comparison between the 3M method and Method 29. The results of the comparison revealed equivalent precision and slight bias high for some of the metals, particularly Cd, Cr, and Pb. Significant amounts of these three metals were also found in the probe wash (up to 40% for Cr), which was attributed to the association of these metals with larger particles (that accumulate in the probe). The association of these metals with larger particles would also explain the biasing high of the results for these metals, since subisokinetic sampling will tend to over sample large particles relative to small ones.

Thus the preliminary testing indicates that:

- Single point sampling is valid in this case.
- Subisokinetic sampling may be acceptable in this case (but is certainly not generally applicable).

- A significant fraction of the sample for some metals accumulates in the probe. A probe rinse therefore appears to be necessary for quantitative metals sampling.

In addition, a critical technical issue that still needs to be resolved is the use of the CIF's. The performance of CIFs are a function of temperature, chlorine concentration, oxygen concentration, sulfur concentration, and other factors. Therefore the range of conditions over which use of CIFs is appropriate needs to be determined.

In summary, the proposed 3M CEMS consists of a simplified sampling methodology (relative to Method 29) to allow continuous sampling of stack emissions. It is a manual method, with the filters changed by hand and sent to an analytical laboratory for Method 29 type analysis. The results of the analysis are therefore not immediately available, and in order to avoid large labor costs, the sampling interval must be long (otherwise too many samples are generated for analysis). Thus, it is not a continuous monitor in the sense implied by the term "CEMS." In fact, this approach suffers from the main limitation of Method 29: the analysis is a complex, time consuming, and costly procedure. Assuming a sampling interval of 24 hours and a per sample analysis cost of $500, the yearly cost for sample analysis alone is $360,000 (a particulate filter and a CIF are generated for analysis each sample period). On the other hand, the only equipment required is the simplified sampling system, thus initial installation costs will be low. It should be noted, however, that this approach may have utility in providing interim compliance monitoring on a time averaged basis until other CEMS are developed. The advantages and disadvantages of this approach are summarized below.

Advantages:

- Only a simple sampling system is required, therefore initial installation costs will be low.
- Established analysis procedures are already developed, therefore development costs will be low.

Disadvantages:

- Although sampling is continuous, averaging times are long and the analysis is not continuous.
- Analysis is complex, time consuming, and costly, with resultant reporting times on the order of weeks.

A.4.3 <u>HEST</u>

The HEST technique employs an isokinetic sampling system with quartz (teflon proposed) filter collection for particulates and CIFs for volatile metals (Cooper et al., 1992). The analysis of both filters is carried out by X-ray fluorescence spectrometry (XRF), which is capable of providing concentrations of all the desired toxic metals except beryllium (Be). In an automated HEST CEMS, a cassette or tape mechanism would remove the filters (replacing them with new ones) and possibly transport them to an on-site XRF spectrometer. The XRF analysis is carried out directly on the filters themselves and is non-destructive. Be analysis, if desired, must be carried out by standard analytical techniques (Method 29).

XRF analysis is capable of potential detection limits (estimates based on detection limits measured to date and improvements that can be realized from optimization of the spectrometer and filter substrate) from roughly 1 to 50 times lower than those of Method 29 (one-twelfth the sample volume, and depending on the metal), with both sampling and analysis/reporting times on the order of tens of minutes (see Table A-9, derived from data provided by Chester Environmental) (Cooper et al., 1993). In the absence of particle size effects, which are not expected to be important for sampling locations downstream of particulate control devices, calibration standards are available which offer accuracies of about 5%.

Chester Environmental (now part of TRC), the developer of HEST, has carried out preliminary testing of the components of a HEST CEMS. The HEST sampling train and off-site XRF analysis combination has been tested on the stack emissions from coal-fired power plants as part of the DOE flue gas clean-up program. Comparison between HEST and Method 29 measurements were made for As, Cd, Cr, Ni, Se, and Hg. The differences between the measurements by the two methods were not statistically significant except in the case of Ni (HEST measurements as much as 50% below the Method 29 values). Agreement was not good for 3 out of the 5 metals reported for one run in which very low metals concentrations were present. This was attributed to contamination of the Method 29 samples. No development of an optimized, integrated system with automated sampling and analysis has taken place, nor is such development planned at this time.

The advantages of the HEST technique are as follows. As in the case of the 3M technique, the use of impingers is eliminated. However, the HEST technique also eliminates the sample preparation process, since the filters can be analyzed directly by XRF. The sample handling and analysis is thus greatly simplified, reducing costs and chances for error. The samples may also be stored indefinitely for later reanalysis, if necessary. In addition, XRF analysis can be accomplished in minutes, the XRF device is compact, and stack detection limits are much better than those of

Method 29 (for the same sample volume). The HEST technique can therefore provide on-site monitoring with potential sample integration and analysis times on the order of tens of minutes. The XRF technique itself is a well established analytical tool, and commercial systems are available. Chlorine and oxygen (from HCl and H_2O) are not expected to cause any analytical interferences.

The disadvantages of the HEST technique are the following. First, Be is not detectable by XRF, so if Be monitoring is desired, then part of the filter must be sent to an analytical lab for analysis by standard procedures. Second, XRF analysis cannot be employed in situations where the particle loading on the filter is not uniform. Such a condition must be recognized and the filter analyzed by standard methods. There are also some interference problems between elements, such as between Ni and Co. Finally, the presence of sulfuric acid can cause physical breakdown of the filters and may also block the adsorption of mercury. Thus more study is required to determine the range of conditions over which mercury capture by CIF is quantitative. Demonstration of quantitative particulate capture meeting Method 5 standards using teflon filters will also need to be demonstrated, and the temperature range over which these filters can be used needs to be determined.

Another potential issue of concern is the fact that XRF spectrometry is sensitive to particle size effects. The attenuation of the fluoresced X-rays as they pass out of the bulk particulate material is energy dependent. Since each element emits at characteristic energies, the attenuation of the signal from each element will be different. This effect can therefore bias the measurements low, and the amount of bias will be different for each element, being more severe the lighter the element and the larger the particles. Clearly, if the particles are small enough, this effect will not be significant, and the XRF analysis is straightforward. Chester Environmental estimates an 8% attenuation for Cr (the worst case among the 10 hazardous elements that can be detected with XRF) for 10 micron carbon and quartz, and 15 micron limestone particles. For this effect to be important, then, a significant fraction of the particles would need to be greater than 10 microns. Table A-10 shows Chester Environmental's estimate of the attenuation for each metal for the case of 10 micron carbon and quartz, and 15 micron limestone particles.

In summary, the proposed HEST CEMS offers batch sampling and on-site analysis with a time resolution on the order of 30 minutes and with detection limits superior to those of Method 29. Issues of concern are: 1) quantitative sampling due to accumulation of sample in the probe (how can a probe rinse, if needed, be incorporated), and 2) the range performance of the teflon and carbon impregnated filters. It is estimated that development of such a system, including prototype assembly and field demonstration, could take place in about 18 months at a cost of approximately $525,000.

Advantages:

- Non-destructive analysis, archivable samples.
- Well established analytical technique (XRF).

- Detection limits generally 10-100 times lower than Method 29 for equivalent sample volumes.

Disadvantages:

- Be is not detectable by XRF.
- Batch sampling/analysis and mechanical sample handling system.
- Reporting times on the order of tens of minutes.

A.4.4 SPICAP

SPICAP is a CEMS developed by MRI for other sensing applications that concentrates the particulate and vapor phase metals into a liquid stream by passing an isokinetically sampled gas stream from the stack through a proprietary liquid scrubber. The liquid containing the sample is then nebulized to generate an aerosol that is entrained into an ICP. Analysis is thus performed by standard liquid sample ICP techniques, although this procedure differs from Method 29 techniques in that the aerosol contains undigested particulates. The extent of the concentration that occurs in transferring the sample from the gas to liquid phase is determined by the ratio of the gas flow rate to the liquid flow rate. As currently proposed by MRI, SPICAP would have detection limits between 1 and 100 times lower than those of Method 29. SPICAP accomplishes this by using sampling rates about 100 times larger than those typically used by Method 29 (300L/min vs. 20L/min) with liquid withdrawal rates of 1 to 10 ml/min. The use of comparable sampling rates and liquid sample sizes in Method 29 would result in detection limits which are the same as those in the proposed SPICAP system. Response time of the SPICAP system is determined by the rate at which scrubber solution is removed (and replaced) and the total liquid volume in the system. Thus there is a trade off between response time and detection limits. Withdrawing solution at a rate of 10 ml/min, with a liquid volume of 150 ml would result in a time constant of about 15 minutes (MRI, 1993a).

SPICAP for use as a metals CEMS is currently at the conceptual stage. However, MRI has built working devices for other applications and is currently developing a system for hexavalent chromium monitoring. Testing of the Cr^{+6} sampling system has revealed the need for probe rinsing and a saturation tower (to prevent evaporation of scrubbing fluid), which increases the liquid volume in the system, and thus the response time. Based on this experience, MRI plans to incorporate a probe rinse in the proposed metals CEMS. To date, MRI has no external support for the development of SPICAP for use as a metals CEMS.

The essential feature of SPICAP is its ability to concentrate the gas phase sample into a liquid stream on a continuous basis. This confers the following advantages. Sample handling and introduction into the analysis instrument is inherently continuous and automatic and is accomplished by a liquid flow system. This feature lends itself to incorporating a continuous probe wash if sample accumulation in the probe is a problem (the wash liquid is simply combined with the rest of the sample in the scrubber). In addition, calibration of the analysis system is easily accomplished by switching from the scrubber to a series of standard calibration solutions (this does not calibrate the sampling efficiency). In fact, an internal standard for monitoring system performance can be realized by doping the feed liquid with a metal not found in the stack emissions. Finally, a standard analytical ICP system is used for analysis, eliminating the need for development of the detection/analysis components of the CEMS.

The liquid sample handling feature also has disadvantages. Volatile metals other than mercury are captured with a nitric acid solution. If this solution is unsatisfactory for mercury capture, then use of a second scrubber containing a permanganate solution will be required. However, the scrubbers can be arranged in series and the mercury analysis carried out by UV absorption, and thus the additional cost is not great. In addition, the liquid scrubbers have relatively low capture efficiencies (ranging from 50 to 90%) which are dependent on particle size. In order to assure complete and consistent sampling, several scrubbers in series may be needed; this will increase the total fluid volume and hence the response time.

There are several issues that need to be addressed in the development of SPICAP. First. the behavior of particulates in the liquid handling system is an unknown and a source of potential problems. Difficulties may exist with the introduction of the particulate containing sample into the ICP and also with the dropout of particles in the flow system and later re-entrainment, leading to memory effects (hysteresis). In addition, incomplete volatilization of particles by the ICP will result in a bias of the measurement towards low values. If particulates prove to be a problem due to any of these effects, MRI proposes to use a continuous microwave digestion system in order to eliminate the particles. Second, the efficiency of particulate and volatile metals capture by the liquid scrubber will also need to be investigated. The particle capture efficiency is known to be dependent on size (less efficient for smaller particles), and both particulate and volatile capture efficiencies may be as low as 50%. One possible solution is to cascade a series of scrubbers, with the scrubbing solution feeding from one unit into the next. A high and consistent sampling efficiency would need to be demonstrated for the calibration to have validity. Finally, the issue of probe accumulation needs to be investigated and incorporation of a continuous probe rinse demonstrated. One possible solution may be to place a scrubber in the probe near the nozzle to capture large particles before they collect on the walls of the probe.

In summary, the proposed SPICAP CEMS offers continuous sampling and on-site analysis with a time resolution on the order of tens of minutes and with detection limits slightly lower than those of Method 29 owing to the high proposed sampling rate of several hundred liters per minute. The technical risks are few: engineering fixes to the problems of sampling efficiency and particle transport are available at the cost of added complexity. It is estimated that development of the

SPICAP system, including prototype assembly and field demonstration, would take 15 months at a cost of $340,000.

Advantages:

- Continuous sampling and transport to the analytical device.
- Probe rinse easily accommodated.
- Well-established analytical technique (standard analytical ICP).
- Detection limits comparable to Method 29 for equal sample volumes.

Disadvantages:

- Separate system required for mercury.
- Response times on the order of tens of minutes.

A.4.5 <u>On-Line ICP</u>

On-line ICP refers to the continuous introduction of a gas sample directly into an ICP. Analysis by AES is then carried out in exactly the same manner as by conventional ICP. ICP analysis is capable of detecting all of the toxic metals of interest. The essential feature of on-line ICP is that it provides truly continuous monitoring (temporal resolution on the time scale of seconds or minutes). Estimated detection limits (based on the results for Ba, Cu, and Sr in the flue gas of a hazardous waste incinerator) derived from the work at China Lake are about a factor of three lower than those for Method 29 (2.5 m^3 sample) for most metals, with the exception of mercury (about two times higher) (Seltzer, 1993). Work at DOE Morgantown, sampling in a coal gasifier, has currently attained detection limits for various hazardous metals that are from 10 to 100 times higher than those for Method 29 (2.5 m^3 sample) (Meyer, 1993).

There are several efforts at on-line ICP CEMS development currently under way, including programs at DOD China Lake, DOE Morgantown, and ADA Technologies, Inc. (under DOE contract). A fourth program at Battelle Memorial Institute in Columbus, OH has been discontinued. Several different approaches for introducing the gas stream into the ICP subject to the flow constraints imposed by isokinetic sampling requirements and ICP input flow rate limitations have been developed and demonstrated, and quantitative measurements of more than a dozen different metals have been demonstrated.

The Naval Air Warfare Center (NAWC) at China Lake, California, has developed and demonstrated an on-line ICP for the measurement of Cu, Ba, and Sr in the flue gas of an incinerator burning pyrotechnic materials. This work used a commercially available air ICP. Such units currently operate at sample gas flow rates of about 1 L/min (total flow rate is 10 to 15 L/min), therefore requiring a sampling interface since the stack gas is sampled isokinetically at 10-20 L/min. The sample interface consisted of an injection loop that is filled at stack sampling rates and then emptied into the ICP at a lower rate. This scheme thus operates in a batch mode, with samples being injected into the ICP 2-3 times a minute. Calibration is accomplished in the laboratory through comparison of signals generated by the introduction of standard aqueous solutions of metals and powders containing known metals concentrations. Field calibration can then be carried out using the standard solutions alone. Measured concentrations of Cu, Ba, and Sr in the incinerator flue gas were on the order of 1000 micrograms per cubic meter and were within a factor of three of concentrations determined by Method 29 sampling. The discrepancy may be due in part to different normalizations of the two data sets and to sample loss in the transfer line from the stack to the ICP (a 50 ft. heated line was used), and is currently being investigated. The efficiency of sample transport to the ICP needs further investigation, and clearly the configuration can be modified to reduce losses. A follow-on effort to develop a CEMS for multi-metals measurement has been funded by the US Army. In this effort, an argon ICP will be used rather than the air ICP employed to date due to the fact that effective excitation temperatures are higher in an Ar fueled ICP, and interference and background due to molecular species are reduced, thus resulting in better sensitivity. Air ICPs are better at volatilizing particles, however, there is a trade off in performance involved. The main tasks that need to be accomplished are: 1) optimization of the plasma operation and emission detection to maximize sensitivity (the metals studied thus far have relatively good signal to noise ratios), 2) characterization and optimization of the sampling interface, and 3) characterization of biases due to possible matrix effects (background from molecular gases due to variable amounts of C containing species, and the presence of N_2 , NO, and OH emission, and particle distribution and loading effects). Estimated detection limits are shown in Table A-11. A prototype CEMS using the new ICP will be installed in a trailer and field tested at the US Army munitions incinerator at Tooele, UT in the spring of 1996.

ADA Technologies in Denver, Colorado, is pursing development of an on-line ICP funded both internally and by an SBIR from DOE Morgantown (Hyatt et al., 1993). Phase I of the SBIR is nearing completion. In the Phase I work, simulated flue gas mixed with 90% argon is excited in an inductively coupled plasma. The ADA system requires dilution of the waste stream with argon to ensure a plasma that is sufficiently hot to vaporize and excite emission from all metals of interest. The metals emission must be detected in the presence of a strong background consisting mainly of NO and OH (A-X) band emission. Using background subtraction techniques, ADA demonstrated detection of Ti, Mg, Si, Al, V, Zn, Na, Fe, Pb, Cr, Mn, and Ba directly as constituents of fly ash and Cd, Se, and Hg in simulated flue gas (Hg and Se simultaneously at 100 ppm levels). Quantitative results have not yet been obtained. ADA plans to develop a field deployable device in Phase II for testing with actual stack gases. ADA is already actively exploring commercialization possibilities with instrument makers.

An in-house program at the Morgantown Energy Technology Center, Morgantown, West Virginia, has developed an on-line ICP for use in analyzing coal-fired gasification and combustion streams (Chisolm, 1993). This system utilizes an He-Ar ICP torch and a sampling interface that allows introduction of low flow rate sample gas to be introduced to the ICP. The sampling system is heated, and the ICP is located at the sample point, with the electronics remotely located. Detection limits are sub ppm for some metals, although there may be problems with Pb and As. Particle size effects may also be a problem. The sample transport efficiency must also be studied to assure that there are no particle dropout problems. Gas phase detection limits available to date are listed in Table A-12.

In summary, the various proposals for on-line ICP metals CEMS offer continuous sampling with real time on-site analysis. Direct sampling and analysis of a gas stream has an advantage in that this is the simplest possible scheme for stack gas sampling, and thus potentially the most reliable. There are no mechanical transport, liquid transport, or wet chemistry considerations. The development efforts at China Lake and DOE Morgantown are the furtherest along: they both have prototypes in operation. However, data for the 11 HAPs metals in a stack stream similar to that of a hazardous waste burning facility are not available. Estimates of the performance of a system optimized for this application are difficult to make, as performance depends on the type of ICP and the characteristics of the flue gas. Based on the work at China Lake, detection limits roughly equivalent to Method 29 with a $2.5m^3$ sample (2 hours at 20 L/min) can be reasonably expected. The work at China Lake has also established a potential calibration protocol. This calibration will not take into account sampling losses. There are several issues of concern that need to be addressed in the development of on-line ICP. Particle drop-out and sample accumulation in flow system between the probe and ICP is potentially problematic. Also there are potential background and bias problems from molecular emission. This may cause problems as water vapor and organic concentrations, and particle loading and size distribution, change. Finally, complete volatilization of particles must be assured.

Advantages:

- Simple, continuous sampling.
- Real-time analysis on the order of minutes.

Disadvantages:

- Characterization of background and interferences is required, and the resultant detection limits are not known with certainty (and will depend on the characteristics of the stack gas).

A.4.6 Laser Spark Spectroscopy (LASS)

LASS is the only "in-situ" method among the five potential CEMS that have been identified. In LASS, a high energy pulsed laser is focused into the gas stream to be analyzed, and gas at the focal volume is dissociated and ionized to form a transient plasma. Particles present in the focal volume are volatilized and also contribute to the plasma. Analysis is accomplished by detecting the atomic emission from the plasma. LASS is thus similar to ICP in that plasma emission is used for metal detection and quantification. However, the laser, rather than an ICP, is the plasma source, and the plasma is created in the gas stream with no need for sampling. LASS is capable of performing continuous monitoring with a time resolution on the order of minutes. Current laboratory detection limits are shown in Table A-13.

LASS is being developed at Sandia National Laboratories in Livermore, CA (Flower et al., 1993 and Otteson et al., 1989). There are still several fundamental issues that are being researched, such as particle effects, background problems, and calibration procedures which need to be developed. In addition, systematic effects that may bias the measurements, such as quenching of the emission, need to be investigated. In a complementary effort, the EPA Office of Research and Development is supporting basic research into these areas at SRI, International in Menlo Park, CA (Dave Crosley's group). A prototype LASS system has been assembled at Sandia, and has made demonstration measurements at a pilot scale Joule melter at Clemson University (Flower et al., 1995). Measurements of Cd at the 4 $\mu g/m^3$ level, Mn at the 14 $\mu g/m^3$ level, and Pb at the 2000 $\mu g/m^3$ level were demonstrated, although the accuracy of the measurements was not assessed through independent measurement or other knowledge of the concentrations. The detection limits determined in the field were from two to four times higher than those determined in the laboratory and listed in Table A-13. In an effort to facilitate bringing this technology to market, Sandia has licenced the LASS technology to a private company which will center its efforts on demonstrating a prototype instrument in the field.

Particle size distribution and loading has the potential to affect LASS measurements. Particles larger than a certain size will not be completely volatilized, which will result in a bias low. Composition of the particles will also be a factor in determining the maximum size that will be completely volatilized. Particle light scattering along the optical path is also a potential problem which may limit the range of conditions for which this approach would be applicable. Routine calibration of an in-situ method such as LASS, required since system performance can be degraded by misalignment (caused by vibration) and dirt (coating the windows and/or optics), is also a difficult issue. Also, detection limits are high due in part to the presence of a large background signal (emission from NO, N_2, and OH from water breakdown, as in the case with on-line ICP). How this background behaves as conditions change can affect performance. Finally, the mechanism of plasma generation in LASS is quite different from that in an ICP, which has been well characterized as an analytical excitation source. It is not known how changing stack conditions will affect the plasma generation and metal emission in LASS.

In summary, the proposed LASS CEMS offers in-situ continuous measurements with a time response on the order of minutes. There are several technical risks: particle effects are largely unknown, background problems must be overcome, and a practical calibration procedure must be developed. The primary attraction of LASS lies in the fact that it is an in-situ technique. This is a major advantage in that questions concerning the efficiency of probe sampling and sample transport are thus eliminated. Calibration of the optical system on the stack will also be required, which is envisioned to involve removing the optics from the stack and interfacing them with a calibration apparatus that includes some type of aerosol generator. This procedure would provide an overall system calibration, but would be cumbersome. Current detection limits are 1 to 50 times higher than those for Method 29. In addition, difficulties associated with bias due to changing conditions, such as water concentration and particle size, are largely unexplored.

Advantages:

- In-situ: no probe or sample transport needs.
- Real-time analysis with response times on the order of minutes.

Disadvantages:

- Calibration: appropriate source needs to be developed, and procedure is likely to be cumbersome.
- Characterization of background and interferences is required, and the resultant detection limits are not known with certainty (and will depend on the characteristics of the stack gas). Current detection limits are higher than those of the other proposed CEMS.

A.4.7 Comparison of Metals CEMS

Current detection limits for the candidate CEMS are compared to Method 29 detection limits in the Table A-14. Potential detection limits for all the candidate CEMS are compared to the average emission levels of three cement kilns during compliance testing and to BIF rule limits calculated assuming a dispersion coefficient of 0.3 and a stack flow rate of 60 m^3/s in Table A-15.

Detection limits averaged over all metals for the various CEMS are shown graphically as a function of sampling time in the Figure A-9. Detection limits for HEST and Method 29 (3M is the same as Method 29) are a function of sample time. Detection limits for SPICAP are a function of sample rate and liquid withdrawal rate, which affect response time. Detection limits for LASS and on-line ICP are not functions of time (collection of sufficient photons takes less than a minute). HEST and SPICAP have the best detection limits, while on-line ICP has potential detection limits equivalent to about a 100 minute Method 29 sample (at 20L/min). Current LASS detection limits are higher, although the goal that the developer hopes to obtain is < 100 $\mu g/m^3$ for all of the HAPs metals.

The detailed discussions of the individual CEMS in the preceding sections are summarized in Tables A-16 and A-17. Initial cost is not included because all of the candidate CEMS are estimated to cost between $100,000 and $200,000 with the exception of the 3M technique, which would cost less than $25,000 (achieved at the expense of much higher operating costs). The terms low, moderate, and high in assessing operating and maintenance costs are relative only (no absolute dollar costs have been determined as there is no experience operating or maintaining these devices in a CEMS application).

A.4.8 Conclusions

Five potential metals CEMS have been identified and evaluated. The results of this evaluation are the following. There are four potential CEMS approaches at different stages of development (HEST, SPICAP, On-line ICP, and LASS), each of which offers a unique combination of advantages and disadvantages. It may be that each will be best suited to differing ranges of stack conditions, and that no one CEMS will be universally applicable. The fifth approach, 3M, is not a true CEMS. It is, rather, "semi-continuous," and may have utility in an interim role, as it has a substantial lead in development.

Two of the approaches, HEST and SPICAP, are based on established analytical techniques. Their development is thus a question of engineering and demonstrating workable prototypes, and establishing the range of conditions to which they can be applied. Since these approaches are extractive, their biggest challenge is in solving the probe accumulation problem. Both of these CEMS have measurement times that will probably be between ten minutes and an hour. HEST has undergone extensive component testing, however, there is currently no backing for the development of a CEMS. SPICAP is the only probe-based CEMS that can easily incorporate a probe wash, and thus side-step the potential probe accumulation problem. Issues to be addressed concern sampling efficiency and transport. The components of a SPICAP CEMS will be field test in the summer of 1995 at the joint DOE/EPA CEMS demonstration project conducted at the IRF in Jefferson, AR.

The other two approaches, On-line ICP and LASS, have great potential as real-time CEMS. However, both have substantial development work remaining to done. The great attraction of LASS is its potential to allow in-situ measurement (avoiding probe accumulation problems), however, this also poses difficult challenges to obtaining quantitative results. A prototype system for field demonstration work is now available, although quantitative results have not yet been obtained.

On-line ICP offers the potential combination of real-time monitoring capability with good performance. Key issues to be addressed are: 1) probe accumulation and 2) quantitative detection in real conditions. Several development efforts are underway, with the program at China Lake being probably the best funded. This effort is on schedule for field testing at an incinerator in the spring of 1996.

A.5 CEMS FOR ORGANIC COMPOUNDS

A.5.1 Introduction

Organic compounds are currently measured using SW-846-0039 (VOST) and SW-846-0010 (Semi-VOST) (EPA Method 18, general organics). These methods involve batch sampling, with organics capture by filter, condensation, adsorption, or simple storage of the gas volume sampled. Analysis is typically by GC/MS (following extraction from the sample medium if necessary). These methods are manual methods and involve time consuming analysis. A need therefore exists for organics measurement technology that is automatic and provides on-site, real-time analysis. There are several technologies that are currently commercially available or under development that have the potential to meet these needs. These technologies are summarized in Table A-18, in which they are organized by type of approach: fast cycle gas-chromatograph (GC), direct sample mass spectrometry (MS), ion-mobility Spectroscopy (IMS), ultraviolet (UV) Spectroscopy, fourier transform infrared (FTIR) Spectroscopy, photoelectric detection for particulate bound PAH, and laser induce fluorescence (LIF) for vapor phase PAH. The detailed information under each heading in the table is intended to represent a sample of the development activity underway, not a comprehensive survey.

A.5.2 Fast Cycle GC

Continuous GC with detection by mass spectrometry, flame ionization (FID), electron capture (ECD), and flame photometry (FPD) are currently under development. With a MS for detection, such a system is capable of species resolution in two dimensions, GC transit time and mass spectrum, and thus provides the highest degree of species specificity. This approach is capable of simultaneous multiple species detection at detection levels two to three orders of magnitude below those of FTIR. Less expensive approaches rely on simpler detection systems, such as FID, ECD, and FPD. These systems rely on the GC to provide most of the specificity, and when a complex mix of species is analyzed, can only distinguish between types of compounds.

There are several efforts underway to develop fast cycle GC for real time stack gas analysis. For instance, the Army has developed an on-line GC system designed to measure chemical warfare agent concentrations using a FPD to detect chemiluminescence from the HPO radical (National Research Council, 1994). The system has suffered from too many false positives and calibration difficulties. A review of the program has recommended development of a GC/MS based system. Also, an automated vapor sampling system coupled to a short capillary GC column that allows sampling times of less than a second and analysis times on the order of minutes has been developed by researchers at the University of Utah This system has used MS, FTIR, and IMS detection (Meuzlar et al., 1994).

Advantages:

- Sensitivity to the ppb level.
- Selective for at least classes of compounds. When coupled to an MS, can be highly selective and sensitive.

Disadvantages:

- Periodic introduction of sample into GC.

A.5.3 Direct Sample MS

Mass spectrometers are capable of multi-species measurements with excellent sensitivity. Groups at both Los Alamos National Labs and Oak Ridge are developing direct sample ion-trap MS. The Los Alamos group is using a direct membrane sampling technology developed at Purdue University. Such a system is capable of response times on the order of minutes with sub-ppb sensitivity (Wong et al., 1995). Other groups are developing mobile MS based instruments, but details are not known at this time. Eli EcoLogic Inc. is marketing a commercially available direct sample mass spectrometer system made by the Austrian firm of V&F (EcoLogic Inc., 1994). This system uses a quadrapole mass spectrometer and "chemical" ionization that results in minimal fragmentation. This results in easier interpretation of mass spectra and enhanced sensitivity. The latest model of this device offers sub ppb sensitivity. This device has been tested on incinerators in Europe, Canada, and the US, and is currently in use on a number of incinerators in Europe. The cost of the unit is approximately $200,000. A potentially significant advancement in MS technology is the development by Westinghouse of a mass spectrometer on a chip. With this technology a complete GC/MS could be reduced to the size of a shoebox, resulting in a revolution in the fieldability and cost of GC/MS based CEMS. Westinghouse plans to be an original equipment supplier to instrument manufacturers who would produce integrated CEMS.

Advantages:

- Excellent sensitivity: sub-ppb.
- Continuous
- Good selectivity

Disadvantages:

- May not have sufficient specificity in HWI stack environment, in which case must couple with GC.
- Expensive, although miniaturization may drastically reduce costs in the future

A.5.4 Ion Mobility Spectroscopy

IMS systems, described in Section A.4.4, are available for some specific organic compounds and for classes of compounds. Typical detection limits are on the order of 1 ppb with response times on the order of 30 seconds (Environmental Technologies Group Inc., 1994). ETG, a maker of IMS CEMS, estimates that they could develop an analyzer for chlorinated organics in 6 months for $50,000. The cost of such a device would also be in the $50,000 range.

Advantages:

- Excellent sensitivity: down to 1 ppb
- Continuous, good time response
- Relatively inexpensive.

Disadvantages:

- Low specificity, but may be good for classes of compounds.

A.5.5 DOAS

The Opsis systems described previously can simultaneously detect some acid gases, NO_x, SO_x, water, and many organics. Opsis is designed for open path measurements and for cross stack monitoring. Detection limits depend on the measurement path length: for a 20 foot path, the detection limit for most species is in the ppm range (ABB Power Plant Controls, 1994). Opsis is TUV approved in Germany.

Advantages:

- Specific compounds can be detected
- Multicomponent measurements.
- In-situ.

Disadvantages:

- Relatively expensive.
- Detection limits not low enough without concentration (but system is designed for in-situ measurements)
- The list of organics that can be detected is restrictive.

A.5.6 FTIR

FTIR systems, described in Section A.4.6, are available from a variety of vendors and work has been underway for several years using FTIR spectrometers for the measurement of organic compounds in ambient air (long path monitoring for fence lines, eg.). The EPA has also been funding the development and validation of FTIR methodology for stack sampling and monitoring (Entropy Environmentalists, Inc., 1993). The FTIR technique is attractive because it is capable of detecting a wide range of compounds (reference spectra for 105 HAPs are currently available) at the 0.5 - 5 ppm level. It can detect multiple compounds simultaneously (up to 10 to 20), and the measurement time is on the order of minutes. Sample concentration is necessary to make measurements at the sub-ppm levels of most PIC's in stacks. The results of recent EPA validation tests using several different sampling techniques were the following: direct sampling of hot, humid stack gas resulted in the quantitative measurement of 23 compounds at the 10 ppm level (21 compounds gave non-valid results), use of a condenser to knock out water vapor gave quantitative results for 24 compounds at the 10 ppm level (22 compounds gave non-valid results), and use of an adsorption/desorption system gave quantitative results for 11 compounds at the 0.5 ppm level (13 compounds gave non-valid results). Factors affecting the results are sample loss in the sample transport system, spectral interferences (water vapor), and efficiency of the sorbent for various compounds. However, no commercial system is currently available that can measure PIC concentrations at the 1 to 100 ppbv level at which most species occur.

Advantages:

- Multicomponent, species specific analysis

Disadvantages:

- Moderately expensive
- Detection limits not low enough without concentration

A.5.7 UV Photo-ionization

A monitor for particle bound PAH using photoelectric detection is commercially available from EcoChem. The measurement is performed on a stack slip-stream that is heavily diluted with ambient air. A UV lamp is used to photo-ionize PAH molecules on the surface of particles. The free electrons are then accelerated by an electric field to an electrode and the resulting current is measured (EcoChem, 1994 and Niessner and Wilbring, 1989). This instrument has been evaluated by the EPA for ambient monitoring (Wilson, et al., 1993), and is currently being evaluated by the Combustion Research Branch of the EPA Office of Research and Development for use as a stack emissions monitor.

In the ambient air evaluation cited above, it is noted that instrument response varies from species to species: the photoelectric threshold is lower for larger PAH. The response is also larger for PAH on smaller particles. Thus quantitative measurements are made by correlating the monitor signal with PAH concentration measured by independent means. It has been found that this calibration is independent of the type of aerosol within a factor of two. Detection limits are on the order of 10 ng/m^3. Instrument response is also likely to be affected by water concentration, which quenches the photoelectric emission. For these reasons, it was concluded that the monitor produces semi-quantitative results and that its use is most appropriate as a screening instrument.

Evaluation of the instrument for stack monitoring by the Combustion Research Branch has also shown a good correlation of instrument response with conventional PAH measurements. Additional field testing by EPA has shown that the instrument can not be used downstream of an ESP (the charged particles generated by the ESP interfere with the measurement). Since about half of all facilities use ESP's, use of this instrument for compliance monitoring does not appear to be feasible.

Advantages:

- Excellent sensitivity to particle borne PAH as a class
- Good time response
- Inexpensive

Disadvantages:

- Only particle bound PAH
- Not quantitative
- Can not be used downstream of an ESP

A.5.8 LIF

Laser Induced Fluorescence has been proposed as a potential monitoring method for PAH and dioxins/furans. The EPA Office of Research and Development has carried out a feasibility study of this approach (Radian Corp., 1993). A previous study (Radian Corp., 1991) had concluded that LIF was the most promising approach to take. As part of the feasibility study, pure vapor spectra of 2,3,7,8-tetrachloro dibenzo-p-dioxin, 1,2,3,7,8-pentachloro dibenzo-p-dioxin, 2,3,7,8-tetrachloro dibenzofuran, octachloro dibenzofuran, and benzo-(a)-pyrene were obtained with detection limits ranging from 0.01 to 24.6 ng/m^3. The spectrum for each of these compounds was unique, with peak positions ranging from 335 to 453 nm. On the basis of this study it was recommended that a LIF system based on excitation at 308 nm using a XeCl laser be developed.

There are, however, many potential problems with this approach. The spectra from large aromatic and chlorinated aromatic hydrocarbons are broad. Thus in actual stack conditions, where many different PAH and chlorinated PAH species are present simultaneously, the resultant spectrum is a superposition of the many individual spectra from which it is unlikely that species specific information can be derived. LIF is also subject to effects that may make quantitative measurement difficult: quenching of the fluorescence, self-absorption, and light scattering by particles. It is doubtful that detection limits in the field would even closely approach those derived from pure component studies in the lab.

The association of broadband fluorescence with PAHs has been known for some time (Miller et al., 1982) in the combustion research community. Prof. Sarofim's group at MIT has correlated PAH fluorescence excited by an argon ion laser at 488 nm with total PAH concentration determined by traditional means, and has a patent pending on their approach (Thijssen et al., 1994). They estimate the detection limit for total PAH to be in the parts per billion range. Because of the difficulties mentioned in the preceding paragraph, and the fact that the fluorescence yield varies from species to species (some do not fluoresce at all), it is not clear that this approach can be used to determine absolute PAH concentrations with confidence. Thus, while LIF appears to be a promising monitor for trends in PAH emission, more research is needed to determine if it can used for compliance purposes. Technolas, a German company, is currently field testing a prototype. Their first series of tests, at an MWC, were not successful due to the fact that actual PAH concentrations were below the detection limit of the instrument. They are currently redesigning the instrument to lower the detection limit, and plan to conduct more field test soon.

Advantages:

- Excellent sensitivity to vapor phase PAH as a class
- Good time response

Disadvantages:

- Only vapor phase PAH
- Not quantitative

A.5.9 Summary and Conclusions

The various organic compound CEMS and their capabilities and other characteristics are summarized in Table A-19. Direct sample mass spectrometry offers the best combination of continuous operation, adequate detection limits, and multiple species resolution/capability. Commercially available systems are already available, and there will soon be many entrants/variants on the market. In stack detection of PIC's has been demonstrated, although further work is needed to demonstrate that the results are quantitative. Optically based instruments, such as DOAS (Opsis) and FTIR systems, offer continuous operation and multi-species capabilities, but do not have sufficient sensitivity to measure chlorobenzene at sub 100 ppbv levels.

It should be noted that, with the exception of the PM bound PAH meter, all of the approaches discussed in this survey are for the measurement of *volatile* organics only. Most semi-volatile and all condensed organics are beyond the capabilities of the CEMS measurement technologies currently under development. Given this limitation, however, it is likely that CEMS capable of measuring volatile and some semi-volatile PIC's could be available in under two years. Since PCDD/F concentrations are so small as to be below any likely detection limits available in the next few years, identification of surrogates from the mixture of PIC's that are detectable is of prime importance.

A.6 SUMMARY AND CONCLUSIONS

A.6.1 PM CEMS

Several different types of device are currently commercially available for continuous monitoring of PM emissions, and many are installed worldwide. Light scattering based devices are TUV approved and used for compliance monitoring in Germany. Use of these devices for compliance monitoring depends on calibration against manual gravimetric methods since they measure a secondary property of the particulate rather than mass. The feasibility of using PM CEMS for compliance therefore hinges on the stability of the calibration as the properties of the particulate change with process conditions. The German experience is that, for well controlled sources, the calibration relation is sufficiently stable. This is supported by demonstration testing conducted in the United States by the U.S.EPA at the Dupont Wilmington hazardous waste incinerator, as described in Section 12.3.3.

A.6.2 Mercury CEMS

Several different approaches to monitoring total mercury are under development, and one device is commercially available. This device has TUV laboratory approval, and is currently undergoing the field trial phase of the certification process. All of the devices have demonstrated at least the ability to measure elemental mercury and mercury chloride. Since these are the major mercury species emitted, monitoring for "total" mercury appears feasible. In fact, in principle these monitors should actually detect all speciated mercury. The one device that is currently available also measures PM bound mercury. Since this is accomplished by thermal desorption, with modification all of the device under development should also be able to measure PM bound mercury. A CEMS for total mercury thus appears feasible, although this needs to be demonstrated through field comparisons with the EPA reference method.

A.6.3 Acid Gas CEMS

Many different types of device for monitoring HCl are currently available and installed worldwide. Several are TUV approved and used for compliance monitoring in Germany. Several have also been tested by the EPA in an HCl CEMS demonstration program and been found to perform satisfactorily. The feasibility of using a CEMS for compliance monitoring of HCl can thus be considered to be established. This is not the case for monitoring of Cl_2. A couple of different monitoring approaches are available: UV DOAS (Opsis) and mass spectrometry. Of these, only Opsis is TUV approved, although not for Cl_2, and only Opsis is widely installed. Monitoring for Cl_2 thus appears to be feasible, but this needs to demonstrated in the field against EPA reference methods.

A.6.4 Multi-metals CEMS

No CEMS for monitoring multi-metals are currently available. Several different technologies are currently under development, and two to three prototype systems are entering the field test phase. Although these devices are promising, by the time any of them reach and pass the demonstration phase against EPA reference methods at least another year will have passed, and it is probably a minimum of two years before any system would be commercially available.

A.6.5 Organics CEMS

A variety of approaches for simultaneously monitoring multiple organic species are under development. Of these, direct sample mass spectrometry is the most promising in due to its low (sub ppb) detection limits. There are many vendors working on this approach, and at least one system is already commercially available. This system has undergone some limited field testing in both Europe and Canada, and is currently installed on three incinerators in Europe. In stack measurement of PIC's at the 1 to 100 ppb level has been demonstrated. However, quantitative measurement still needs to be demonstrated by comparison with EPA reference methods in a field trial in this country. In addition, there is a need for detailed PIC emission data from hazardous waste burning facilities in order to determine which species to regulate and at what levels. If demonstration of a CEMS for PIC's is successful, then there is strong potential for surrogate (eg., chlorobenzene) monitoring for PCDD/F.

TABLE A-1. SUMMARY OF PM CEMS

Type	Principle	Maker	Available/Cost	Address/Phone/Contact
O	Opacity	Monitor Labs, Inc. & Others	Yes	74 Inverness Dr. East Englewood, Co 80112 (303) 792-3300 Sarah Hamilton
O	Time Dependent Transmission	BHA	Yes $15K	8800 East 63rd St. Kansas City, MO 64133 (816) 356-8400 Mark Santschi
O	Forward Scatter	Insitec	Yes $28K	2110 Omega Rd., Suite D San Ramon, CA 94583 (510) 837-1330 Michael Bonin
O	Back Scatter	Environmental Systems Corp.	Yes $10K	200 Tech Center Dr. Knoxville, TN 37912 (615) 688-7900 Robert Nuspliger
O	90° Scattering	Sick Optic-Electronic Inc. (Germany)	Yes $18K	7694 Golden Triangle Dr. Box 444-240 Eden Prairie, MN 55344 (612) 941-6780 Stephen Wisker
E	Beta Gauge	Emission S.A. (France)	Yes $35K	Environment U.S.A. 302 Capistrano Ave. Shell Beach, CA 93449 (805) 773-4255 Tony Griguoli
E	Oscillating Element	Ruprecht & Pataschnick Co., Inc.	Yes	25 Corporate Circle Albany, NY 12203 (518) 452-0065
P	Triboelectric	Auburn International, Inc.	Yes $10K	8 Electronics Ave. P.O. Box 2008 Danvers, MA 01923 (508) 777-2460 Chris Reiner
P	Acoustic Energy	Jonas, Inc.	Yes $12K	1113 Faun Rd. Wilmington, DE 19803 (302) 478-1375 Ravi Mathur

TABLE A-2. SUMMARY OF PM CEMS PERFORMANCE SPECIFICATIONS

Principle	Maker	Load Range	Size Range	Issues
Time-dependent Transmission	BHA	0.000004 - 4 gr/dscf	0.3 - 75 µm	1) Response depends on particle composition and size distribution. 2) Must assume particle density (calibrate) to obtain mass measurement.
Forward Scatter	Insitec	0.006 - > 1 gr/dscf	1 - 100 µm	1) Response depends to some extent on particle composition and size distribution (less so than for back scattering and opacity). 2) Must assume particle density (calibrate) to obtain mass measurement.
Back Scatter	Env. Systems Corp.	0.0005 - 8 gr/dscf	0.05 - 10 µm	1) Response depends on particle composition and size distribution. 2) Must assume particle density (calibrate) to obtain mass measurement.
Side Scatter	Sick Optic	$2X10^{-6}$ - 0.01 gr/dscf	0.1 - 50 µm	1) Response depends on particle composition and size distribution. 2) Must assume particle density (calibrate) to obtain mass measurement.
Tribo-electric	Auburn	> $5X10^{-5}$ gr/dscf	> 0.5 µm	1) A mass response will depend on resistivity and density of the particles. 2) Small particles will follow the flow and not impact the probe. 3) Effect in (2) and limited sensitivity to smaller particles means response will be dependent on size distribution and velocity.
Acoustic Energy	Jonas, Inc.	0 - 0.05 gr/dscf estimated for typical stack conditions (depends on flow velocity, size distribution, and density).	> 10 um	1) Response depends on particle velocity. 2) Small particles will follow the flow and not impact the probe. 3) Effect in (2) and limited sensitivity to smaller particles means response will be dependent on size distribution.
Beta Gauge	Emissions S.A.	1.25 mg/m^3 based on a sampling time of two minutes	All	1) Losses in extractive sampling.

TABLE A-3. PARAMETERS AFFECTING PM CEMS

Type/Principle	Parameter/Issue
Optical	1. Particle size distribution 2. Composition (through effect on index of refraction). 3. Density
Probe/Tribo-electric	1. Particle size distribution 2. Flow velocity 3. Resistivity 4. Density
Probe/Acoustic Energy	1. Particle size distribution 2. Flow velocity
Extractive/Beta Gauge	1. Sampling Losses

TABLE A-4. SUMMARY OF PM CEMS REGULATIONS

	German Regulation (for PM CEMS)	**EPA Regulation**
Sensitivity to temperature in the range of -20 to 50 C	< 2% of full scale	None
Sensitivity to supply voltage fluctuations of -15 to +10 %	< 2% of full scale	None
Response to a set of internal calibration standards	+/- 2% of value of standard	None
Zero point drift	< 2% over the maintenance interval	<2.5% during 7 day check of performance. specs, during normal operation <5% per day (requires recalibration). Drift is excessive if >5% for 5 consecutive days or >10% at any check, and maintenance is required. Check required at least once per day.
Sensitivity drift	< 2% over the maintenance interval	Same as above
Automatic sensitivity correction	< 6% over the maintenance interval	Same as above
Data Availability	> 90 %	None
Instrument response check (see section A.2.1 item 3)	Yearly	Quarterly cylinder gas audits
Calibration check (against manual reference method)	Every 3 to 5 years	Yearly RATA's

TABLE A-5. SUMMARY OF MERCURY CEMS

Maker	Available/Cost	Address/Phone/Contact
PSI	Under development	Physical Sciences, Inc. 20 New England Business Center, Andover, MA 01810 (508) 689-0003 Larry Piper
ADA	Under development	ADA Technologies, Inc. 304 Inverness Way South Suite 110 Englewood, CO 80112 (303) 792-5615 Richard Schlager
Verewa	Yes, $130K	Euramark 834 E. Rand Rd., Suite 6 P.O. Box 823 Mount Prospect, IL 60056 Hans Brouwers
Senova	Under development, estimated cost $50K	Senova Corp. 1435 N. Hayden Rd. Scottsdale, AZ 85257 (602) 970-6355 Ian Sorensen
ABB (Elemental only)	Yes, $120K	ABB Power Plant Controls 2 Waterside Crossing Windsor, CT 06095 (203) 285-6893 Gary Teodosio

TABLE A-6. SUMMARY OF ACID GAS CEMS

I. NDIR Based

Maker	Available/Cost	Address/Phone/Contact
Bodenseewerk	Yes (S) $150 - 200K (HCl and NOx, SOx, CO, CO2, H20, CH4, NH3)	Altech Systems Corp. 11969 Challenger Ct. Moorpark, CA 93021 (805) 529-9955 Rich Brown
Servomex Co., Inc.	Yes (S) $30K (HCl)	90 Kerry Place Norwood, MA 02062 (800) 862-0200 Lynne Baron
Air Instruments and Measurements, Inc. (AIM)	Yes (S) $40 K (in-situ) $55 K (hot/wet extractive) (HCl, multi-component CEMS also available)	13111 Brooks Dr., Suite D Baldwin Park, CA 91706 (818) 813-1460 Harold Lord
Thermo Environmental Instruments Inc. (TECO)	Yes (S) $12K (HCl)	Eight West Forge Parkway Franklin, MA 02038 (508) 520-0430 John Mclean

II. Ion Selective Electrode Based

Maker	Available/Cost	Address/Phone/Contact
TessComm	Yes (S) $25K (HCl)	P.O. Box 600 Clairton, PA 15025 (412) 233-5782 Lou Colonna
Bran & Luebbe	Yes (S) $60K (HCl. Units also available for HF)	Analyzing Technologies, Inc. 103 Fairview Park Dr. Elmsford, NY 10523 (708) 520-0700 Tom Iervolino
Compur	No information available	
Kyoto	No longer marketed in the US	
Severn Science Instruments	Yes (S) $40K (HCl)	Mission Instruments 26705 Loma Verde Mission Viejo, CA 92691 (714) 582-0889 George Sotter

III. Ion Mobility Spectroscopy Based

Maker	Available/Cost	Address/Phone/Contact
Environmental Technologies Group, Inc. (ETG)	Yes (S) $15K ($Cl_2$ & HCl, F_2 & HF, Br_2 & HBr, I_2)	1400 Taylor Ave. P.O. Box 9840 Baltimore, MD 21284 (410) 339-3146 Alan Bickel

IV. UV Spectroscopy Based

Maker	Available/Cost	Address/Phone/Contact
ABB Power Plant Controls	Yes (S) (Cl_2, HCl, HF, and many others) $125K	2 Waterside Crossing Windsor, CT 060095 (203) 285-6796 Mike Hartman
Ametek	Yes, but not for stack sampling. (HCl)	455 Corporate Blvd. Newark, DE 19702 (800) 222-6789 Brian Reed

V. Colormetric Based

Maker	Available/Cost	Address/Phone/Contact
MDA	Yes, but not for high H2O applications. No hot/wet sampling system. Thus not appropriate for HWI stacks.	405 Barclay Blvd. Lincolnshire, IL 60069 (800) 344-4632

VI. FTIR Based

Maker	Available/Cost	Address/Phone/Contact
KVB	Yes (S) < $100K	9342 Jeronimo Irvine, CA 92718 (714) 587-2300 William Cottrell (703-694-5778)
Enviroplan	Yes (S)	3 Becker Farm Rd. Roseland, NJ 07068 (201) 994-2300
Rosemount	Yes (S)	1201 North Main St. P.O. Box 901 Orrville, OH 44667 (800) 628-1200

VI. MS Based

Maker	Available/Cost	Address/Phone/Contact
Extrel	Yes (A) $120K w/o sampling system. (HCl, Cl_2, HF, F_2, I2, Br_2, HBr)	575 Epsilon Dr. Pittsburgh, PA 15238 (713) 661-6569 Joe Schwab
Fisons	Yes (A)	32 Commerce Center Cherry Hill Dr. Danvers, MA 01923 (508) 777-8034 Jason Cape

TABLE A-7. SUMMARY OF ACID GAS CEMS

Type	Detection Limit	Species	Comments
NDIR	Approx. 1 ppm	HCl	- Inexpensive - Multicomponent for major species
ISE	Sub-ppm	HCl	- Inexpensive
IMS	Sub-ppm	Total HCl + Cl2	- Inexpensive - Systems for HF and F_2, HBr and Br_2, I_2, Cl_2O also
UV	Approx. 1 ppm	HCl, Cl_2, HF	- In-situ - Multicomponent - Expensive
FTIR	Approx. 1 ppm	HCl, HF, HBr	- Multicomponent - Moderately expensive
MS	Sub-ppm	All acid gases	- Multicomponent - Expensive

TABLE A-8. LIST OF METALS CEMS DEVELOPERS

Developer	Method	Contact	Address	Phone Number
3M	3M	Dana Schnobrich	3M Co. St. Paul, MN 55133	612-458-2500
Chester Environmental	HEST	John Cooper	12242 S.W. Garden Place, Tigard, Oregon 97223	503-624-2773
Midwest Research Inst.	SPICAP	Gary Hinshaw	425 Volker Blvd. Kansas City, MO, 64110	816-753-7600
NAWC China Lake	On-line ICP	Mike Seltzer	NAWC-Weapons Div. China Lake, CA 93555	619-939-1608
DOE Morgantown	On-line ICP	Bill Chisholm		304-291-4730
ADA Technologies	On-line ICP	Mike Durham	304 Inverness Way South Englewood, CO 80112	303-792-5615
Sandia - Livermore	LASS	Nina Bergen-French	Sandia National Laboratories, Livermore, CA	510-294-2046

TABLE A-9. HEST DETECTION LIMITS (µg/m^3)

Element	HEST[a]	HEST[b]	HEST[c]	HEST[d]
Sb			0.096	0.360
As	0.01	0.012	0.029	0.120
Cd	0.052	0.080	0.096	0.360
Cr	0.020	0.02	0.029	0.120
Pb			0.058	0.240
Hg	0.006	0.006	0.048	0.144
Ni	0.008	0.016	0.029	0.120
Se	0.005	0.006	0.029	0.120

(2.5m^3 sample at 20L/min takes 2 hours, 0.2m^3 sample at 20L/min takes 10 minutes)
a - Particles, 2.5m^3 sample, to date
b- Vapor, 2.5m^3 sample, to date
c- Particles, 0.2m^3 sample, potential
d- Vapor, 0.2m^3 sample, potential

TABLE A-10. X-RAY ATTENUATION FACTORS

Element	Attenuation Factor
Cr	0.92
Mn	0.93
Ni	0.96
Zn	0.95
Hg	0.98
As	0.98
Se	0.99
Pb	0.99
Cd	1.0
Sb	1.0

TABLE A-11. ESTIMATED ON-LINE ICP DETECTION LIMITS

Element	**Solution Detection Limit (ug/L)**	**Airborne Detection Limit (ug/m^3)**
Sb	40	61
As	30	4
Be	0.1	0.01
Cd	2	0.2
Cr	3	0.3
Co	3	0.5
Pb	25	3
Mn	1	0.2
Hg	12	2
Ni	4	0.6
Se	30	5

TABLE A-12. MORGANTOWN ICP DETECTION LIMITS

Element	Detection Limit ($\mu g/m^3$)[1]
As	390
Cd	12
Ca	0.095
Cr	1.1
Fe	5.1
Pb	140
Mg	0.23
Hg	430
Se	2400
Ti	1.6
V	1.4
Zn	190

[1] R.R. Romanowski, A.S. Viscomi, and W.P. Chisholm, Paper 662, Book of Abstracts-The Pittsburgh Conference, 1991

TABLE A-13. LASS DETECTION LIMITS

Element	**Detection Limit (μg/m^3)**
As	15
Sb	35
Be	<0.1
Cd	2
Cr	1
Co	2
Pb	250
Mn	<0.25
Hg	15
Ni	40
Se	160

TABLE A-14. CURRENT DETECTION LIMITS [μg/m^3]

Element	Method 29[a]	Method 29[b]	HEST[c]	HEST[d]	SPICAP[e]	On-line ICP[f]	LASS
Sb	3.8(0.35)	1.9(0.2)		0.360	1.6		35
As	6.4(0.15)	3.2(0.05)	0.01	0.012	2.6	390	15
Be	0.035 (0.025)	0.029 (0.015)			0.015		<0.1
Cd	0.5(0.01)	0.25 (0.005)	0.052	0.080	0.2	12	2
Cr	0.85(0.1)	0.4(0.05)	0.020	0.020	0.35	1.1	1
Pb	5.0(0.1)	2.5(0.05)			2.1	140	250
Mn	0.25(0.1)	0.1(0.05)			0.1		<0.25
Hg	0.3	1.5	0.006	0.006	0.01	430	15
Ni	1.8	0.9	0.008	0.016	0.75		40
Se	9.0(0.25)	4.5(0.15)	0.005	0.006	3.8	2400	160

(2.5m3 sample at 20L/min takes 2 hours, 0.2m3 sample at 20L/min takes 10 minutes)
a - Front half, 2.5m3 sample, ICP (GFAAS)
b - Back half, 2.5m3 sample, ICP (GFAAS)
c - Particles, 2.5m3 sample, to date
d - Vapor, 2.5m3 sample, to date
e - sample rate 200L/min, liquid flow rate 10 ml/min, 150 ml liquid volume, for a 15 minute time constant
f - DOE Morgantown

TABLE A-15. POTENTIAL DETECTION LIMITS [μg/m^3]

Element	Average Emissions	BIF Rule Limits	HEST[a]	HEST[b]	SPICAP[c]	On-line ICP[d]	LASS
Sb			0.096	0.360	1.6	6	35
As	2.28	128	0.029	0.120	2.6	4	15
Be	0.57	230			0.015	0.01	<0.1
Cd	34.8	311	0.096	0.360	0.2	0.2	2
Cr	9.6	44	0.029	0.120	0.35	0.3	1
Pb	215	5000	0.058	0.240	2.1	3	250
Mn			0.029		0.1	0.2	<0.25
Hg	5.15	4400	0.048	0.144	0.01	2	15
Ni			0.029	0.120	0.75	0.6	40
Se			0.029	0.120	3.8	5	160

(2.5m^3 sample at 20L/min takes 2 hours, 0.2m^3 sample at 20L/min takes 10 minutes)
a - Particles, 0.2m^3 sample, potential
b - Vapor, 0.2m^3 sample, potential
c - sample rate 200L/min, liquid flow rate 10 ml/min, 150 ml liquid volume, for a 15 minute time constant
d - China Lake, estimated

TABLE A-16. COMPARISON OF METALS CEMS

CEMS	Advantages	Disadvantages	Technical Issues	Operating Costs	Maintenance (Costs)
3M	Low development and installation costs	Long sampling times, manual, off-site analysis: "Semi-Continuous"	CIF performance	High: labor, filters, analysis	Low
HEST	archivable samples, good detection limits (<<M29), easy calibration	Extractive sampling, Be not detectable by XRF, batch sampling and analysis: response time on order of tens of minutes	Probe accumulation, CIF performance	Low: filters	Moderate: potential problems with sample handling
SPICAP	Continuous liquid sampling system, probe rinse and calibration easy, good detection limits (<M29)	Separate scrubber required for Hg, response time on the order of tens of minutes	Particle capture and transport, particle size effects	Moderate: scrubber solution, ICP feed gases	Moderate-High: liquid handling system, nebulizer, and ICP may require frequent maintenance requiring some skill
On-line ICP	Simple, continuous sampling; real-time analysis	Extractive sampling, ultimate detection limits not known and background dependent (estimated =M29)	Probe accumulation, particle size effects, background	Moderate: ICP feed gasses	Moderate: ICP maintenance? (some skill required)
LASS	In-situ	Ultimate detection limits not known and background dependent (estimated >M29), current detection limits >>M29	Particle size and background effects	Low: few consumables	Moderate: Laser maintenance?, Optics cleaning and alignment (skill required)

TABLE A-17. STATUS OF METALS CEMS

CEMS	Current stage of development	Development Time	Backing	Patent protection	Measurement time
3M	essentially developed	essentially developed	3M	No	days
HEST	some component testing, established technology	< 2 years	Chester Environmental, needs sponsors, has potential sponsors	Yes	< hour
SPICAP	conceptual, established technology	< 2 years	MRI internal, needs sponsors	Yes	< hour
On-line ICP	proof of concept laboratory testing, some prototype development	maybe < 2 years	1. DOD internal,. 2. DOE internal. 3. ADA internal, DOE SBIR, sponsors for commercialization. 4. Battelle internal, needs sponsors	1. No 2. No 3. Yes? 4. ?	minutes
LASS	proof of concept laboratory testing	probably > 2 years	Sandia, DOE	No?	minutes

TABLE A-18. SUMMARY OF ORGANIC COMPOUND CEMS

I. Fast Cycle GC

Maker/Developer	Available/Cost	Address/Phone/Contact
EPA Combustion Research Branch	No Vapor phase organics	(919) 541-2854 Jim Kilgroe
Army Chemical Warfare Agent Disposal Program	No Vapor phase chemical warfare agent	(410) 671-3337 Jerry Queen Ballistic Research Lab Aberdeen Proving Grounds, MD
University of Utah Dept. of Mechanical Engineering	No Vapor phase organics	(801) 581-8431 Bill McClennen

II. Direct Sample MS

Maker/Developer	Available/Cost	Address/Phone/Contact
DOE/Los Alamos National Labs	No Vapor phase organics	(505) 665-5735 Philip Hemberger
DOE/Oak Ridge National Labs	No Vapor phase organics	(615) 574-4862 Mark Wise
Entropy Environmentalists	No information available	(919) 781-3550 Laura Kenner
Extrel	Process MS available, $120K w/o sampling system	575 Epsilon Dr. Pittsburgh, PA 15238 (713) 661-6569 Joe Schwab
Hewlett Packard	Process MS available	3495 Deer Creek Rd. Palo Alto, CA 94304 (800) 227-9770
Finnigan MAT	Process MS available	355 River Oaks Parkway San Jose, CA 95134

III. Ion Mobility Spectroscopy Based

Maker/Developer	Available/Cost	Address/Phone/Contact
Environmental Technologies Group, Inc. (ETG)	No 6 months & $50K to develop for classes of organics	1400 Taylor Ave. P.O. Box 9840 Baltimore, MD 21284 (410) 339-3146 Alan Bickel

IV. UV Spectroscopy Based

Maker/Developer	Available/Cost	Address/Phone/Contact
ABB Power Plant Controls	Yes (S) Vapor phase organics $125K	2 Waterside Crossing Windsor, CT 060095 (203) 285-6796 Mike Hartman

V. FTIR Based

Maker/Developer	Available/Cost	Address/Phone/Contact
KVB	Yes (S) Vapor phase organics < $100K	9342 Jeronimo Irvine, CA 92718 (714) 587-2300 William Cottrell (703-694-5778)
Enviroplan	Yes (S) Vapor phase organics	3 Becker Farm Rd. Roseland, NJ 07068 (201) 994-2300
Rosemount	Yes (S) Vapor phase organics	1201 North Main St. P.O. Box 901 Orrville, OH 44667 (800) 628-1200

VI. UV Photo-Ionization

Maker/Developer	Available/Cost	Address/Phone/Contact
EcoChem	Yes (S) Particle bound PAH $25K	22605 Valerio West Hills, CA 91307 (818) 347-4369 E. Chikhliwala

VII. LIF

Maker/Developer	Available/Cost	Address/Phone/Contact
Technolas	No Vapor phase PAH. Field testing technique developed at MIT.	Frankfurt, West Germany 011-49-89-858560 Thomas Weber

TABLE A-19. SUMMARY OF ORGANIC COMPOUND CEMS

Type	Detection Limit	Species	Comments
GC	ppb range	classes of organics and speciation	- periodic sample injection - several development efforts
MS	sub-ppb	speciated organics	- expensive - several development efforts - process instruments available from many makers
IMS	ppb range	classes of organics	- inexpensive - estimated 6 months & $50K to develop
UV	ppm range	speciated organics	- limited number of species detectable - in-situ - expensive
FTIR	ppm range	speciated organics	- concentrating sampling systems for lower detection limits under development - many makers
UV Photo-ionization	ng/m^3 range for total PAH	Particle bound PAH	- inexpensive - commercially available - not compatible with ESP's
LIF	ppb range for total PAH	Vapor phase PAH	-prototype field testing

FIGURE CAPTIONS

Figure A-1. Example of CEMS calibrations carried out at three different plant operating conditions.

At each condition the particulate properties (for example, size distribution and/or index of refraction) are different. The spread of the data points at each condition is due to variation in PM mass loading for constant properties at that condition. The three dashed lines represent least squares linear fits to the CEMS response vs. actual PM loading at each condition. The correlations at each condition between CEMS response and PM loadings are good and distinctly different.

Figure A-2. Example of a single calibration based on data at three different plant operating conditions.

This figure shows a single linear least squares fit (dashed line) to all of the data from the three conditions shown in Figure A-1. The solid lines represent the 95% confidence interval of the fit. Note that the effect of performing a single fit to all of the data, which contains variation in the PM properties, compared to the three fits at each condition shown in Figure A-1: the scatter of the data around the single fit is larger. However, this figure illustrates how the practice of performing a CEMS calibration over a range of plant operating conditions that may have varying PM properties works. The varying PM properties cause the scatter in the data, which is quantified by the 95% confidence bounds placed on the calibration. Specification of how good the correlation and how small the uncertainty must be can be achieved by setting a minimum value of the correlation coefficient and a maximum uncertainty at the emission limit for acceptance of the calibration.

Figure A-3. Calibration of Sick RM200.

This figure shows the data from the first calibration of the Sick RM200 at a secondary lead smelter described in the TUV certification report. The dashed line is the linear least squares fit to the data which establishes the calibration relation between the RM200 output and the PM loading as determined by the manual reference method. The curved solid lines closest to the dashed line are the 95% confidence bounds on the calibration relation. Thus, if the RM200 output is 10 mA, using the calibration relation gives a PM loading of about 2.95 mg/m3 with a 95% confidence that the true PM loading is between 2.7 and 3.2 mg/m3. The solid lines furthest from the dashed line represent the tolerance interval bounding 75% of the population of all comparisons between the RM200 and the reference method at the 95% confidence level. That is, based on the data set shown, one can expect that for further testing that 75% of the data will fall inside the tolerance interval. Thus, the tolerance interval provides a criterion for judging, based on future comparisons of the RM200 with reference method data, whether the new data is consistent with the calibration relation. Both sets of solid lines, the confidence interval for the calibration relation and the tolerance interval, only extend as far as there is test data reflecting the fact that these statistical statements are valid only in the PM range covered by the calibration. In fact, the calibration relation itself is only considered valid in this range also.

Figure A-4. Calibration check for Sick RM200.

This shows the same calibration relation and statistical bounds from Figure A-3 for the first calibration of the RM200 with data overlaid from the second and third calibrations. One can see that, although the data seems to be biased low with respect to the calibration relation, better than 75% of the data (11 out of 14 the points that are within the range of calibration 1) is bounded by the tolerance interval, and is thus consistent with the first calibration. Note that some of the data from calibrations two and three spans a wider range that was covered by the first calibration. This data cannot be rigorously compared to the first calibration, however, it also appears to be consistent with calibration 1 when the solid lines representing the tolerance interval are extrapolated.

Figure A-5. Calibration of the Sick RM200 based on all of the data.

This figure shows the data from all of the calibrations performed during the suitability testing of the RM200. The master calibration relation based on all of this data, 95% confidence interval, and tolerance limits, as explained in the discussion of figure 3, are shown also (the solid lines for the confidence and tolerance intervals are not extended quite to the upper limit of the calibration range due to a fault in the graphics software). Note that with this many data points that the confidence interval for the calibration relation is very small, about +/- 4% at the middle of the calibration range.

Figure A-6. Comparison of initial calibration to all of the data.

This figures shows a comparison between all of the calibration data and the calibration relation and confidence and tolerance intervals for calibration one (solid lines). The dashed line is the master calibration relation from Figure A-5. The first calibration relation and confidence and tolerance intervals are consistent with all of the data and the master calibration within the range of the first calibration.

Figure A-7. Reproducibility of the reference method measurements.

This figure shows the reproducibility of the duplicate reference method measurements taken during calibration three. The dashed line is a least squares fit to the data. Deviation of the data from this line represents the uncertainty associated with the measurements.

Figure A-8. Reproducibility of the Sick RM200 measurements.

This figure shows the reproducibility of the RM200 measurements taken using units 4 and 5 during calibration three. The dashed line is a least squares fit to the data. Note that the uncertainty of the RM200 measurements is considerably less than that of the manual measurements shown in Figure A-7.

Figure A-9. Multi-metals CEMS detection limits.

Stack detection limits for the HEST, SPICAP, LASS, and on-line ICP multi-metals CEMS under development and for Method 29 are shown as a function of sampling time. Note that on-line ICP and LASS have no sample collection, and thus the detection limits are independent of time.

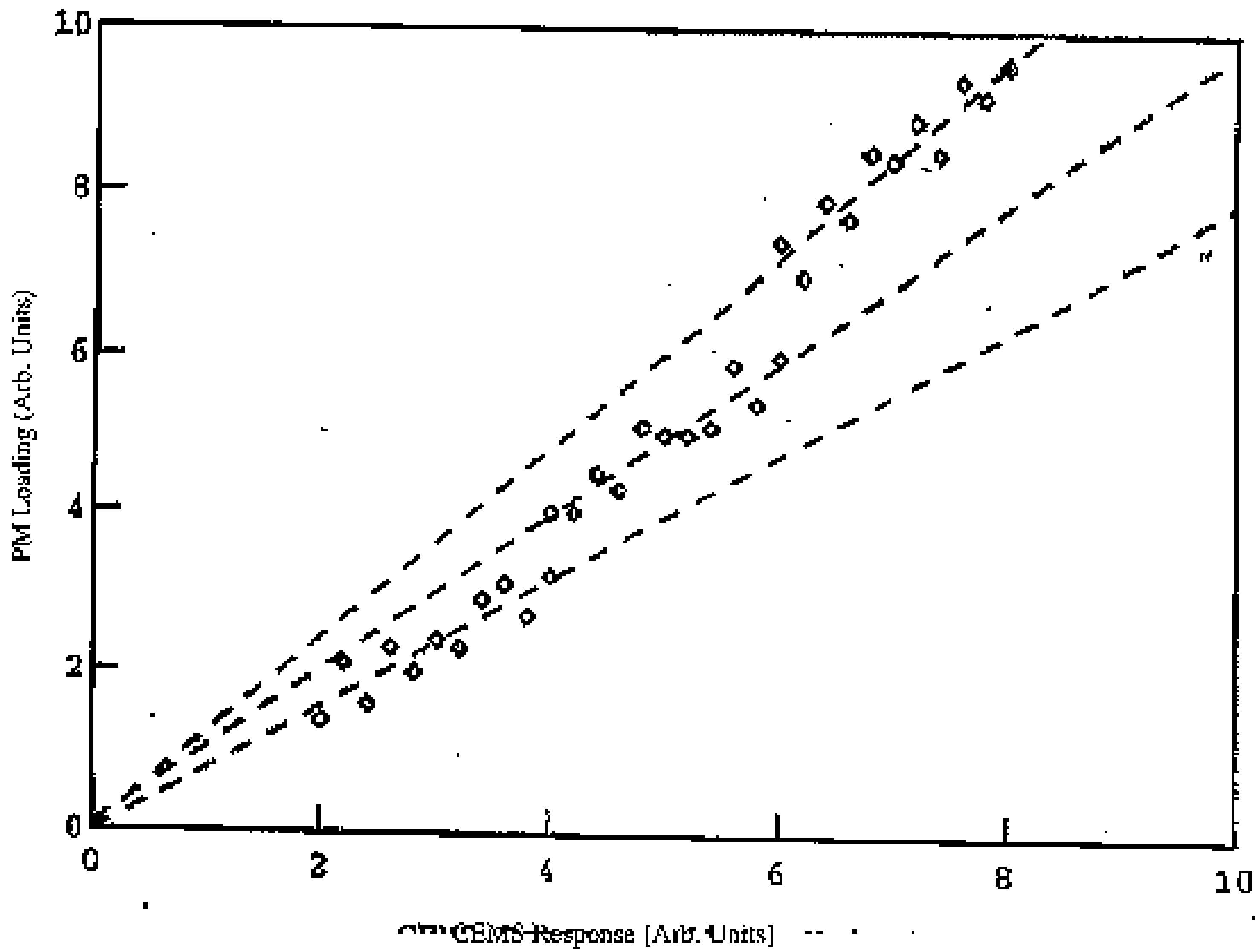


Figure A-1. Example of CEMs calibrations carried out at three different plant operating conditions.

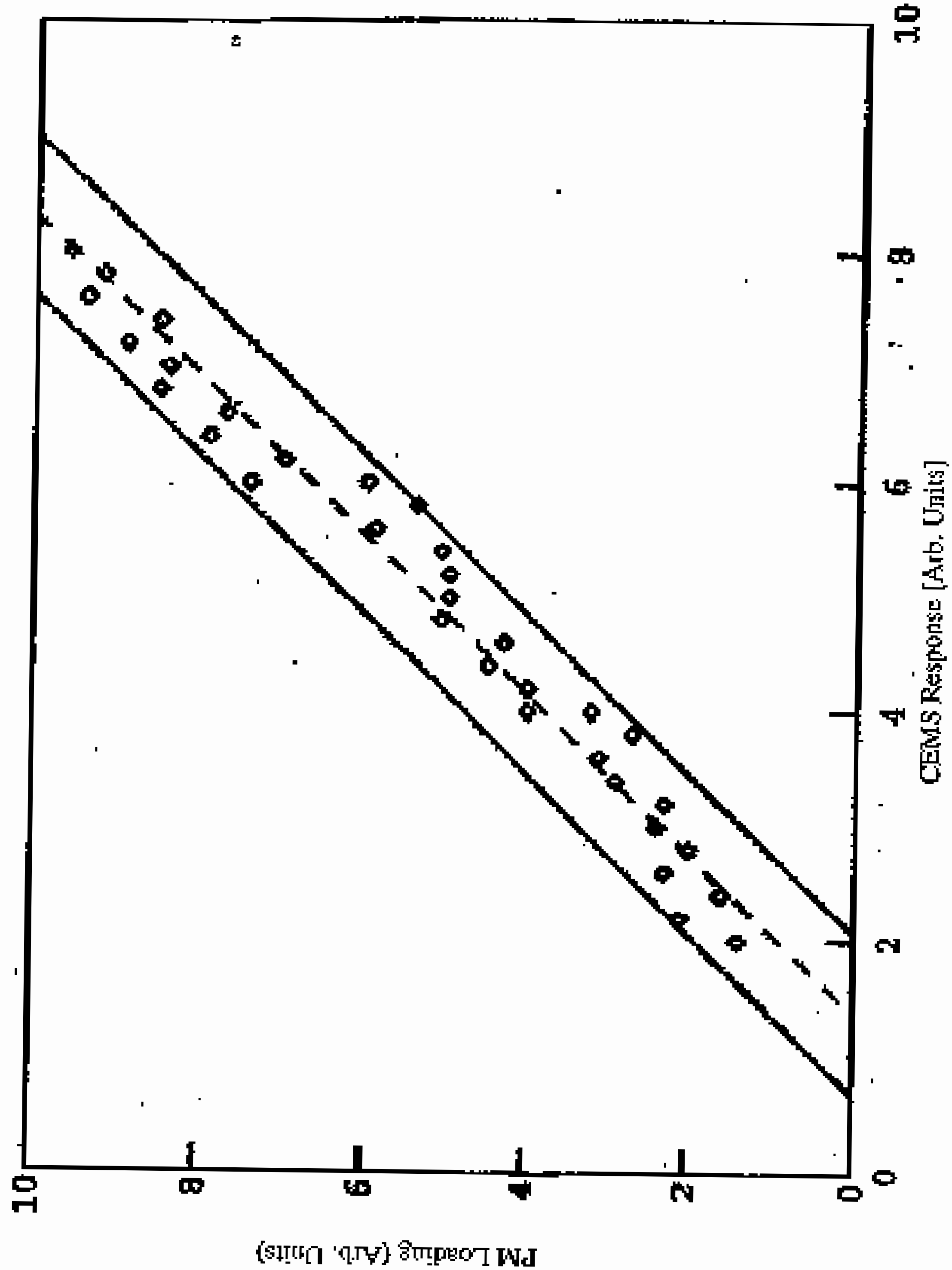
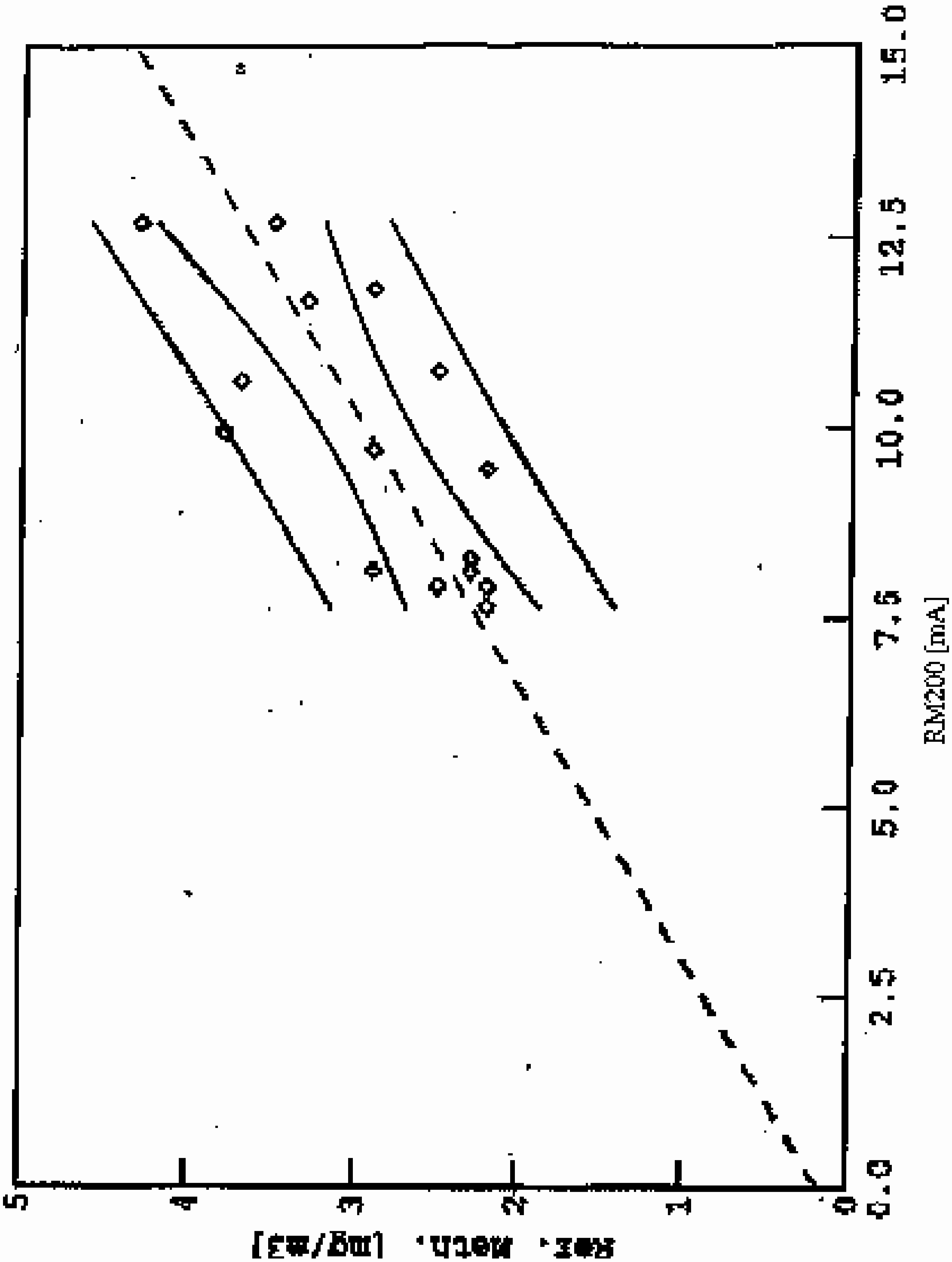


Figure A-2. Example of a single calibration based on data at three different plant operating conditions.



FigureA-3. Calibration of Sick RM200.

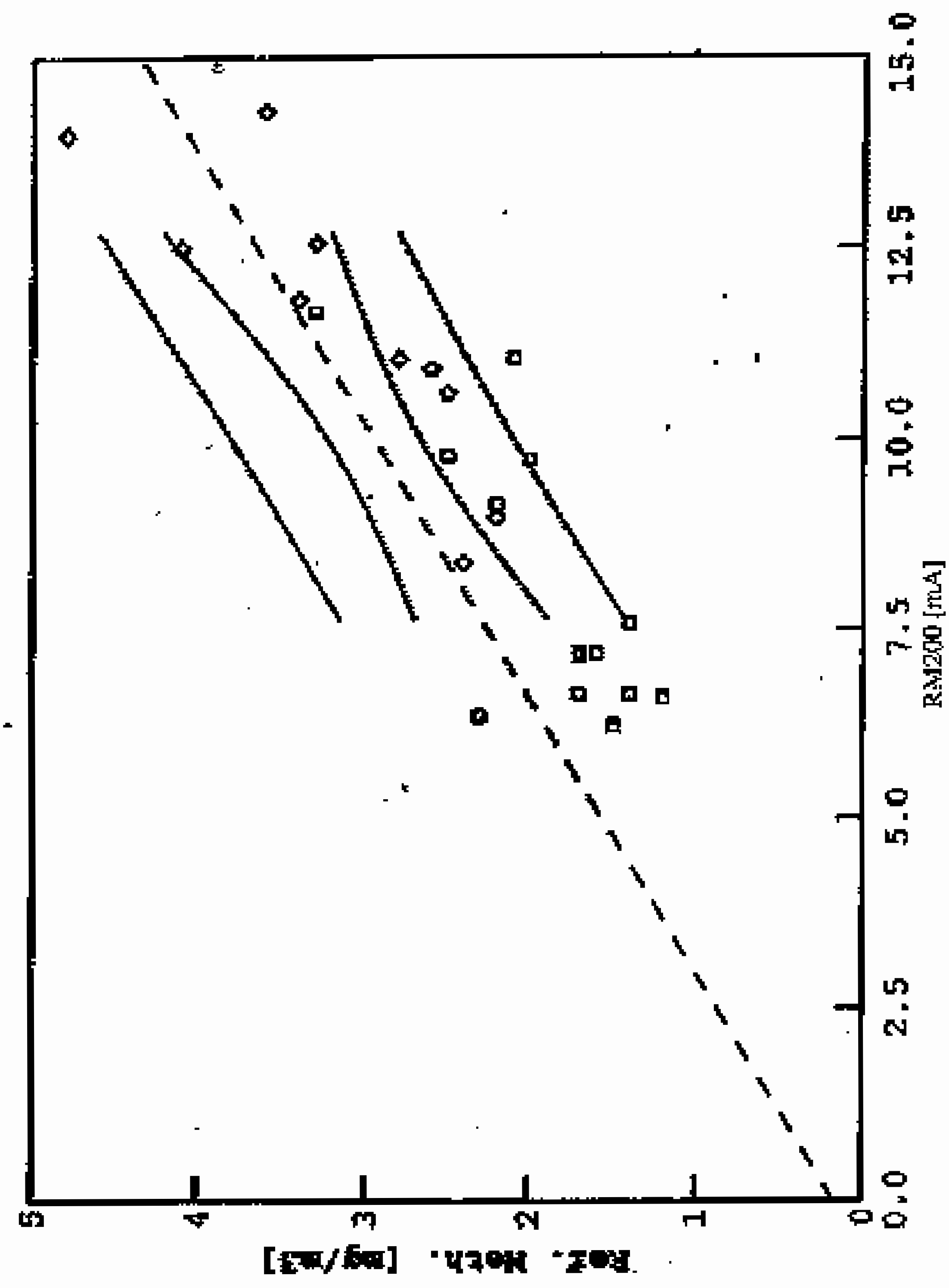


Figure A-4. Calibration check of Sick RM200.

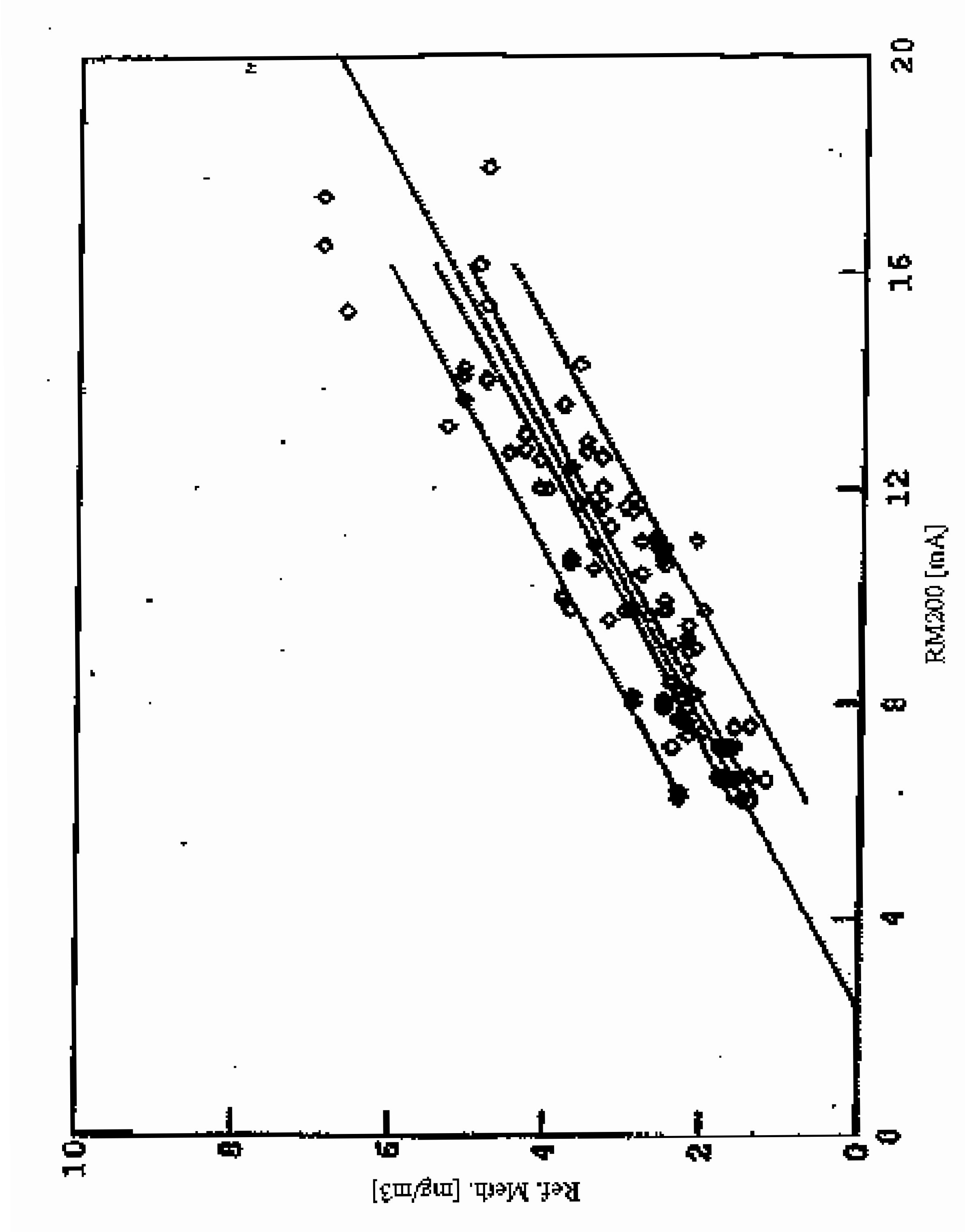


Figure A-5. Calibration of the Sick RM200 based on all of the data.

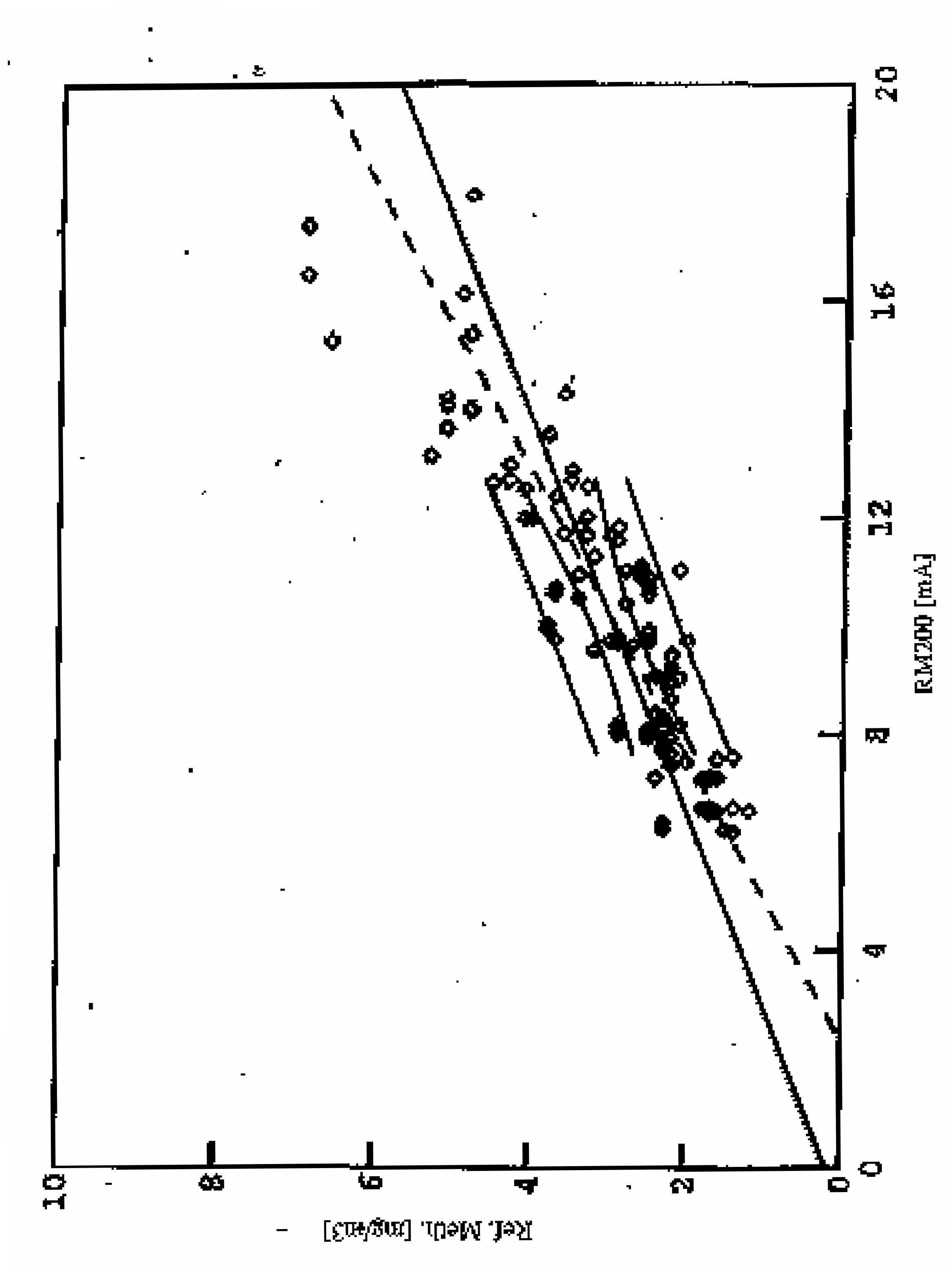


Figure A-6. Comparison of initial calibration to all of the data.

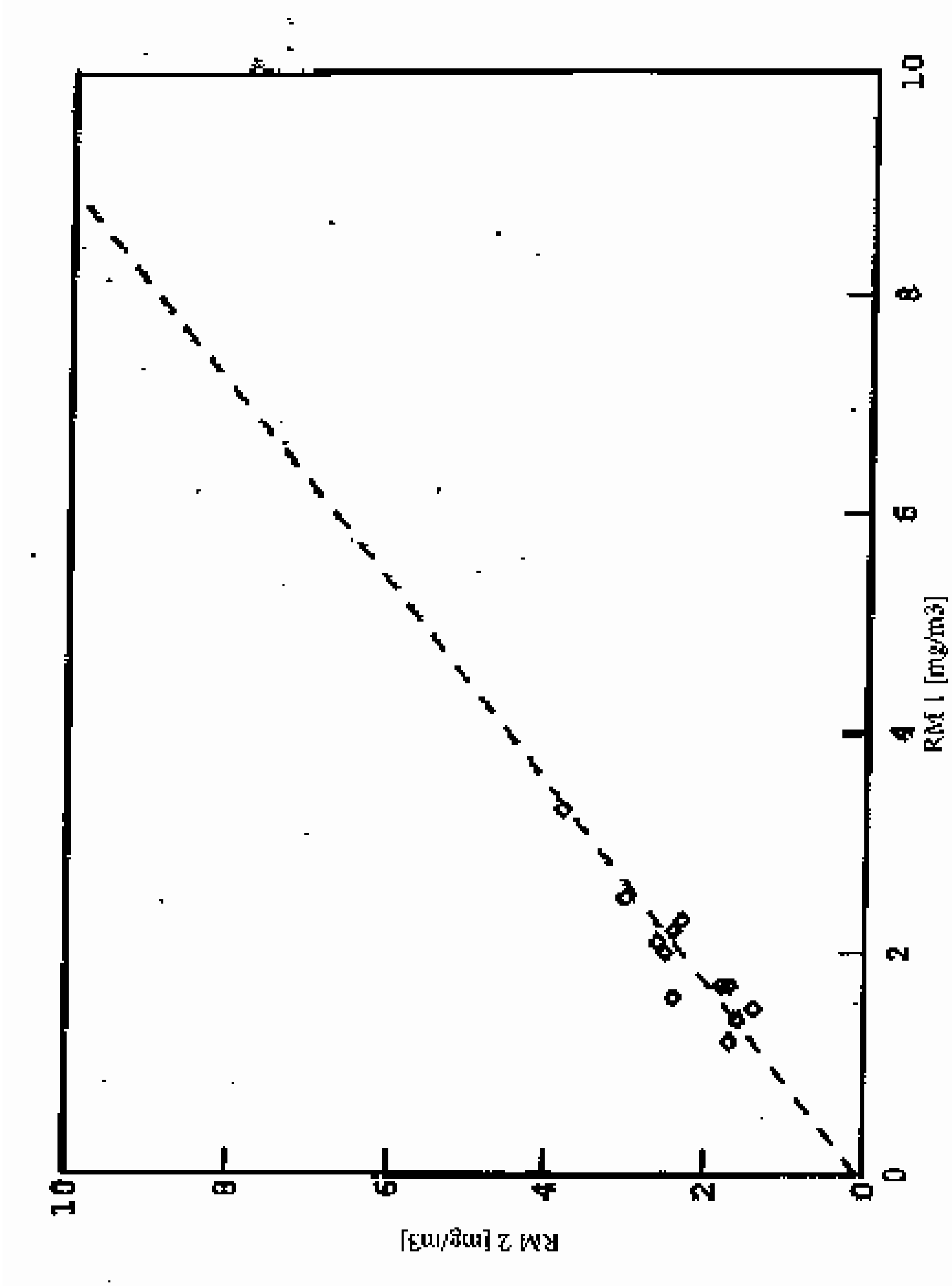


Figure A-7. Reproducibility of the reference method measurements.

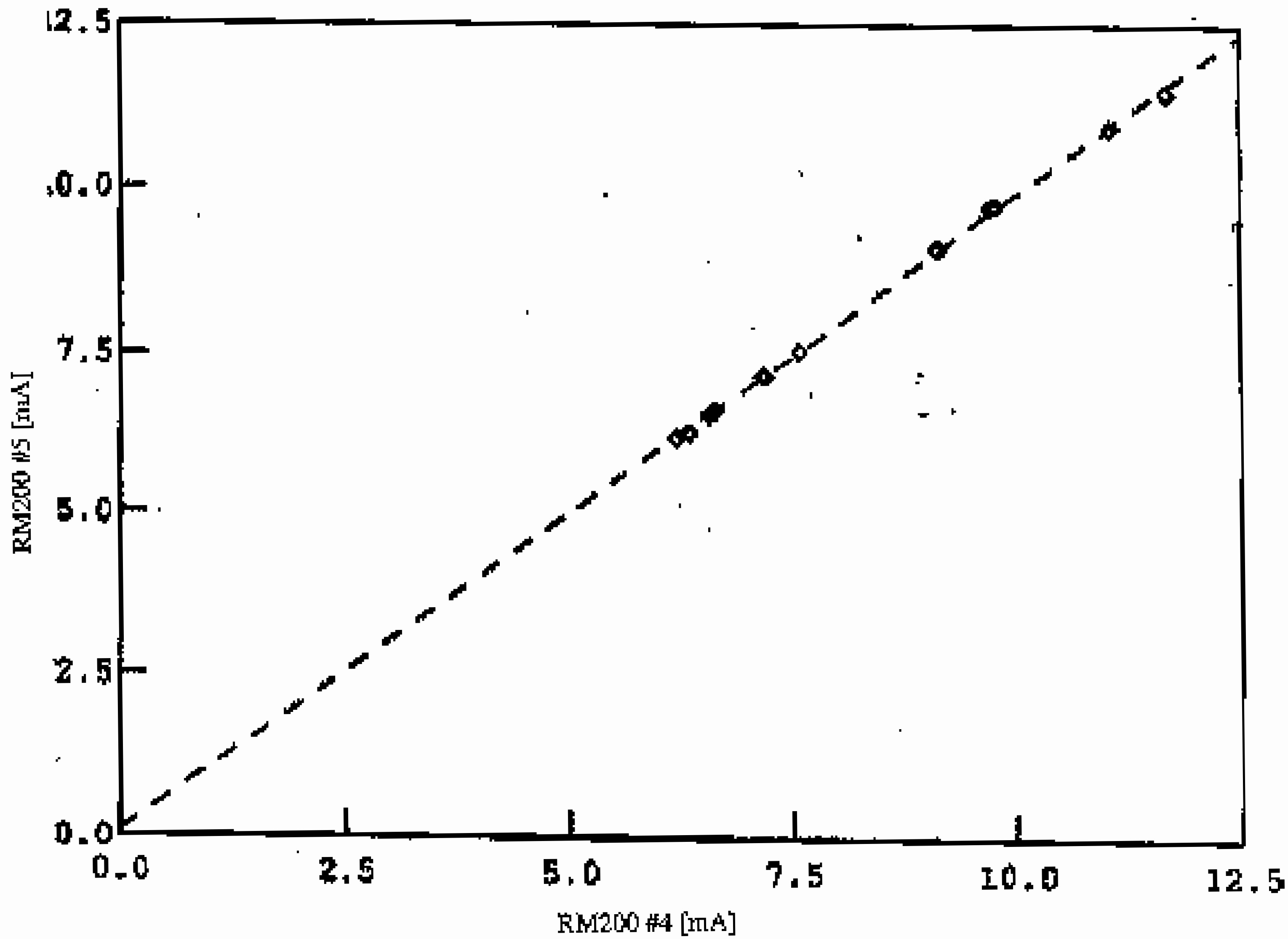


Figure A-8. Reproducibility of the RM200 measurements.

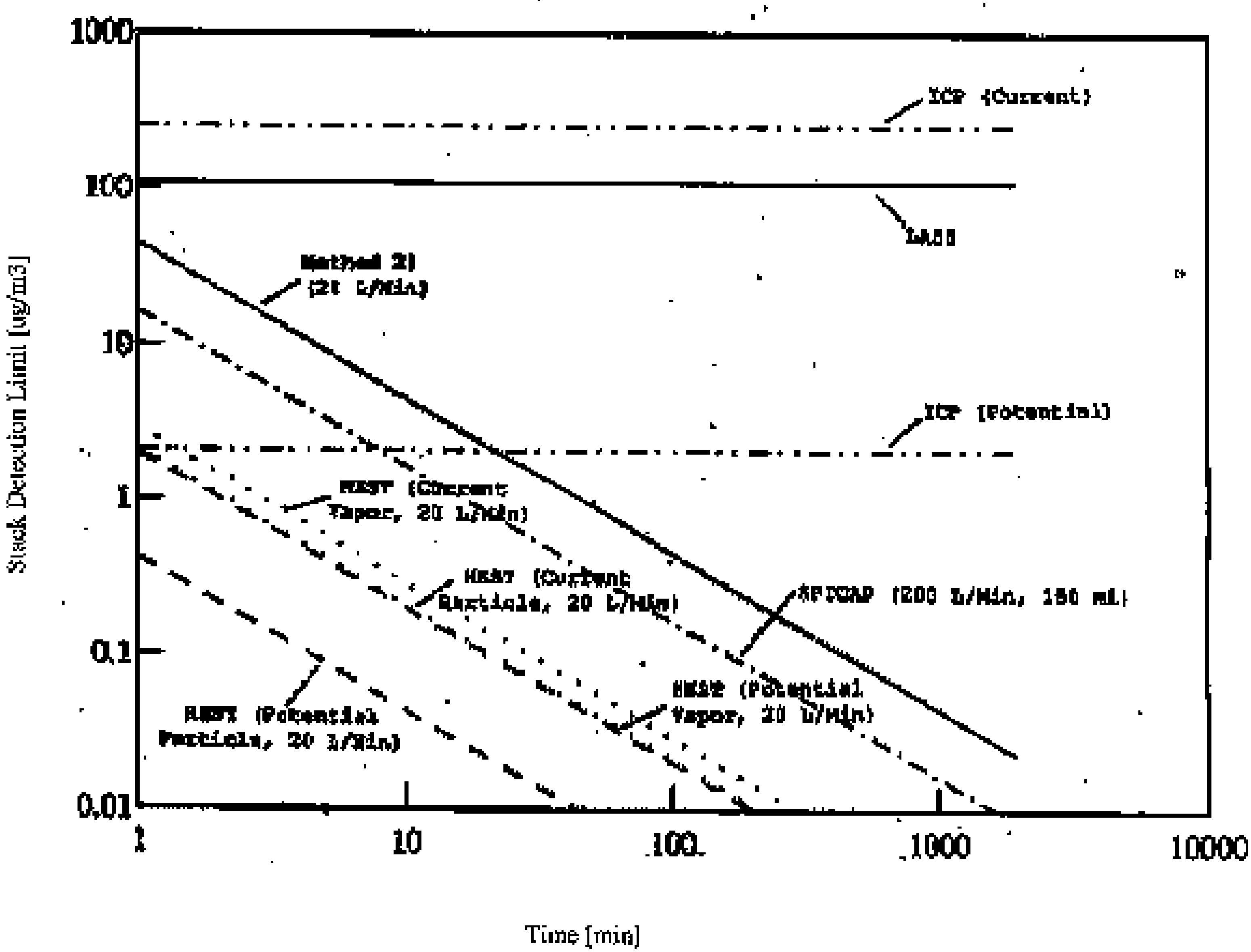


Figure A-9. Multi-metals CEMs detection limits.

APPENDIX B

COMPARABLE FUEL SPECIFICATIONS -- BENCHMARK FUEL ANALYTICAL DATA

COMPARATIVE FUELS RESULTS - PHYSICAL PARAMETERS

Sample	Method	Analyte	Fuel = Gasoline		Fuel = No.2		Fuel = No.4		Fuel = No.6	
			Quant-itation	D.F.	Quant-itation	D.F.	Quant-itation	D.F.	Quant-itation	D.F.
8835-001	EPA 325.3/Parr	Total Halogens as Cl- (ppmw)	< 25	1	< 25	1	< 10	1	< 10	1
8835-001	ASTM D240	Heating Value* (BTU/lb)	19510	1	19580	1	19420	1	18350	1
8835-001	ASTM D1298	Specific Gravity (@ 60 F)	0.759	1	0.864	1	0.892	1	0.988	1
8835-001	ASTM D4629	Total Nitrogen as N	8	1	203	1	2930	1	8950	1
8835-001	SW-846 1010	Flash Point (F)	< 0	1	54	1	66	1	81	1
8835-001	ASTM D445	Kinematic Viscosity (cSt @ 100 F)	N/A		2.91	1	6.4	1	531	1
8835-002	EPA 325.3/Parr	Total Halogens as Cl- (ppmw)	< 25	1	< 25	1			< 10	1
8835-002	ASTM D240	Heating Value* (BTU/lb)	19390	1	19610	1			18720	1
8835-002	ASTM D1298	Specific Gravity (@ 60 F)	0.761	1	0.864	1			0.995	1
8835-002	ASTM D4629	Total Nitrogen as N	8	1	213	1			1860	1
8835-002	SW-846 1010	Flash Point (F)	< 0	1	53.5	1			68.5	1
8835-002	ASTM D445	Kinematic Viscosity (cSt @ 100 F)	N/A		2.87	1			98	1
8835-003	EPA 325.3/Parr	Total Halogens as Cl- (ppmw)	< 25	1	< 25	1			< 10	1
8835-003	ASTM D240	Heating Value* (BTU/lb)	19680	1	19820	1			18410	1
8835-003	ASTM D1298	Specific Gravity (@ 60 F)	0.761	1	0.85	1			0.995	1
8835-003	ASTM D4629	Total Nitrogen as N	6	1	110	1			1820	1
8835-003	SW-846 1010	Flash Point (F)	< 0	1	48	1			73	1
8835-003	ASTM D445	Kinematic Viscosity (cSt @ 100 F)	N/A		2.66	1			98	1
8835-004	EPA 325.3/Parr	Total Halogens as Cl- (ppmw)	< 25	1	< 25	1			< 10	1
8835-004	ASTM D240	Heating Value* (BTU/lb)	19420	1	19760	1			18220	1
8835-004	ASTM D1298	Specific Gravity (@ 60 F)	0.762	1	0.85	1			1.04	1
8835-004	ASTM D4629	Total Nitrogen as N	6	1	104	1			2210	1
8835-004	SW-846 1010	Flash Point (F)	< 0	1	44.5	1			117	1
8835-004	ASTM D445	Kinematic Viscosity (cSt @ 100 F)	N/A		2.73	1			322	1
8835-005	EPA 325.3/Parr	Total Halogens as Cl- (ppmw)	< 25	1	< 25	1			< 10	1
8835-005	ASTM D240	Heating Value* (BTU/lb)	19190	1	19760	1			18140	1
8835-005	ASTM D1298	Specific Gravity (@ 60 F)	0.758	1	0.851	1			1.04	1
8835-005	ASTM D4629	Total Nitrogen as N	22	1	186	1			2150	1
8835-005	SW-846 1010	Flash Point (F)	< 0	1	47.5	1			112	1
8835-005	ASTM D445	Kinematic Viscosity (cSt @ 100 F)	N/A		3.5	1			331	1
8835-006	EPA 325.3/Parr	Total Halogens as Cl- (ppmw)	< 25	1	< 25	1			< 10	1
8835-006	ASTM D240	Specific Gravity (@ 60 F)	19920	1	19890	1			18620	1
8835-006	ASTM D1298	Specific Gravity (@ 60 F)	0.721	1	0.862	1			0.991	1
8835-006	ASTM D4629	Total Nitrogen as N	11	1	341	1			5260	1
8835-006	SW-846 1010	Flash Point (F)	< 0	1	77	1			82	1
8835-006	ASTM D445	Kinematic Viscosity (cSt @ 100 F)	N/A		4.36	1			656	1

COMPARATIVE FUELS RESULTS - PHYSICAL PARAMETERS

Sample	Method	Analyte	Fuel = Gasoline		Fuel = No.2		Fuel = No.4		Fuel = No.6	
			Quant-itation	D.F.	Quant-itation	D.F.	Quant-itation	D.F.	Quant-itation	D.F.
8835-007	EPA 325.3/Parr	Total Halogens as Cl- (ppmw)	< 25	1	< 25	1			< 10	1
8835-007	ASTM D240	Heating Value* (BTU/lb)	19370	1	19570	1			18560	1
8835-007	ASTM D1298	Specific Gravity (@ 60 F)	0.744	1	0.859	1			0.99	1
8835-007	ASTM D4629	Total Nitrogen as N	12	1	165	1			5310	1
8835-007	SW-846 1010	Flash Point (F)	< 0	1	60	1			92.5	1
8835-007	ASTM D445	Kinematic Viscosity (cSt @ 100 F)	N/A		2.34	1			668	1
8835-008	EPA 325.3/Parr	Total Halogens as Cl- (ppmw)	< 25	1	< 25	1				
8835-008	ASTM D240	Heating Value* (BTU/lb)	19550	1	19860	1				
8835-008	ASTM D1298	Specific Gravity (@ 60 F)	0.733	1	0.846	1				
8835-008	ASTM D4629	Total Nitrogen as N	17	1	98	1				
8835-008	SW-846 1010	Flash Point (F)	< 0	1	61.5	1				
8835-008	ASTM D445	Kinematic Viscosity (cSt @ 100 F)	N/A		2.6	1				
8835-009	EPA 325.3/Parr	Total Halogens as Cl- (ppmw)			< 25	1				
8835-009	ASTM D240	Heating Value* (BTU/lb)			19940	1				
8835-009	ASTM D1298	Specific Gravity (@ 60 F)			0.851	1				
8835-009	ASTM D4629	Total Nitrogen as N			43	1				
8835-009	SW-846 1010	Flash Point (F)			72	1				
8835-009	ASTM D445	Kinematic Viscosity (cSt @ 100 F)			3.49	1				
8835-010	EPA 325.3/Parr	Total Halogens as Cl- (ppmw)			< 25	1				
8835-010	ASTM D240	Heating Value* (BTU/lb)			20000	1				
8835-010	ASTM D1298	Specific Gravity (@ 60 F)			0.853	1				
8835-010	ASTM D4629	Total Nitrogen as N			42	1				
8835-010	SW-846 1010	Flash Point (F)			71	1				
8835-010	ASTM D445	Kinematic Viscosity (cSt @ 100 F)			3.71	1				
8835-011	EPA 325.3/Parr	Total Halogens as Cl- (ppmw)			< 25	1				
8835-011	ASTM D240	Heating Value* (BTU/lb)			19740	1				
8835-011	ASTM D1298	Specific Gravity (@ 60 F)			0.86	1				
8835-011	ASTM D4629	Total Nitrogen as N			219	1				
8835-011	SW-846 1010	Flash Point (F)			58	1				
8835-011	ASTM D445	Kinematic Viscosity (cSt @ 100 F)			2.87	1				

N/A - Not Applicable

COMPARATIVE FUELS RESULTS - METALS (mg/Kg)

Sample	Method	Analyte	***Fuel = Gasoline***				***Fuel = No.2***				***Fuel = No.4***				***Fuel = No.6***			
			Q.L.	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**
8835-001	7040	Antimony	<6.67	BQL	U	13.4	<5.84	BQL	U	11.7	<11.5	BQL	U	22.9	<10.2	BQL	U	20.4
8835-001	7060	Arsenic	<0.13	BQL	U	13.4	<0.12	BQL	U	11.7	<0.23	BQL	U	22.9	<0.20	BQL	U	20.4
8835-001	7080	Barium	<13.4	BQL	U	13.4	<11.7	BQL	U	11.7	<22.9	BQL	U	22.9	<20.4	BQL	U	20.4
8835-001	7090	Beryllium	<0.67	BQL	U	13.4	<0.58	BQL	U	11.7	<1.15	BQL	U	22.9	<1.02	BQL	U	20.4
8835-001	7130	Cadmium	<0.67	BQL	U	13.4	<0.58	BQL	U	11.7	<1.15	BQL	U	22.9	<1.02	BQL	U	20.4
8835-001	7190	Chromium	<1.34	BQL	U	13.4	<1.17	BQL	U	11.7	<2.29	BQL	U	22.9	<2.04	BQL	U	20.4
8835-001	7200	Cobalt	<2.67	BQL	U	13.4	<2.34	BQL	U	11.7	<4.59	BQL	U	22.9	<4.08	BQL	U	20.4
8835-001	7420	Lead	<6.67	BQL	U	13.4	<5.84	13.1		11.7	<11.5	19.2		22.9	<10.2	31.4		20.4
8835-001	7460	Manganese	<0.67	BQL	U	13.4	<0.58	BQL	U	11.7	<1.15	BQL	U	22.9	<1.02	BQL	U	20.4
8835-001	7470	Mercury	<0.10	BQL	U	1.00	<0.10	BQL	U	1.00	<0.18	BQL	U	1.00	<0.17	BQL	U	1.00
8835-001	7520	Nickel	<2.67	BQL	U	13.4	<2.34	BQL	U	11.7	<4.59	31.9		22.9	<4.08	106		20.4
8835-001	7740	Selenium	<0.13	BQL	U	13.4	<0.12	BQL	U	11.7	<0.23	0.25		22.9	<0.20	0.28		20.4
8835-001	7760	Silver	<1.33	BQL	U	13.4	<1.17	BQL	U	11.7	<2.29	BQL	U	22.9	<2.04	BQL	U	20.4
8835-001	7840	Thallium	<13.4	BQL	U	13.4	<11.7	BQL	U	11.7	<22.9	BQL	U	22.9	<20.4	BQL	U	20.4
8835-002	7040	Antimony	<6.66	BQL	U	13.3	<5.83	BQL	U	11.7					<10.1	BQL	U	20.3
8835-002	7060	Arsenic	<0.13	BQL	U	13.3	<0.12	BQL	U	11.7					<0.20	BQL	U	20.3
8835-002	7080	Barium	<13.3	BQL	U	13.3	<11.7	BQL	U	11.7					<20.3	BQL	U	20.3
8835-002	7090	Beryllium	<0.66	BQL	U	13.3	<0.58	BQL	U	11.7					<1.01	BQL	U	20.3
8835-002	7130	Cadmium	<0.66	BQL	U	13.3	<0.58	BQL	U	11.7					<1.01	BQL	U	20.3
8835-002	7190	Chromium	<1.33	BQL	U	13.3	<1.17	BQL	U	11.7					<2.03	BQL	U	20.3
8835-002	7200	Cobalt	<2.66	BQL	U	13.3	<2.33	BQL	U	11.7					<4.06	BQL	U	20.3
8835-002	7420	Lead	<6.66	BQL	U	13.3	<5.83	10.4		11.7					<10.1	40.4		20.3
8835-002	7460	Manganese	<0.66	BQL	U	13.3	<0.59	BQL	U	11.7					<1.01	BQL	U	20.3
8835-002	7470	Mercury	<0.10	BQL	U	1.00	<0.10	BQL	U	1.00					<0.17	BQL	U	1.00
8835-002	7520	Nickel	<2.66	BQL	U	13.3	<2.33	BQL	U	11.7					<4.06	6.8		20.3
8835-002	7740	Selenium	<0.13	BQL	U	13.3	<0.12	0.18		11.7					<0.20	BQL	U	20.3
8835-002	7760	Silver	<1.33	BQL	U	13.3	<1.17	BQL	U	11.7					<2.03	BQL	U	20.3
8835-002	7840	Thallium	<13.3	BQL	U	13.3	<11.7	BQL	U	11.7					<20.3	BQL	U	20.3
8835-003	7040	Antimony	<6.67	BQL	U	13.4	<5.94	BQL	U	11.9					<10.1	BQL	U	20.2
8835-003	7060	Arsenic	<0.13	BQL	U	13.4	<0.12	BQL	U	11.9					<0.20	BQL	U	20.2
8835-003	7080	Barium	<13.4	BQL	U	13.4	<11.9	BQL	U	11.9					<20.2	BQL	U	20.2
8835-003	7090	Beryllium	<0.67	BQL	U	13.4	<0.59	BQL	U	11.9					<1.01	BQL	U	20.2
8835-003	7130	Cadmium	<0.67	BQL	U	13.4	<0.59	BQL	U	11.9					<1.01	BQL	U	20.2
8835-003	7190	Chromium	<1.33	BQL	U	13.4	<1.19	BQL	U	11.9					<2.02	BQL	U	20.2
8835-003	7200	Cobalt	<2.67	BQL	U	13.4	<2.38	BQL	U	11.9					<4.04	BQL	U	20.2
8835-003	7420	Lead	<6.67	BQL	U	13.4	<5.94	9.26		11.9					<10.1	40.5		20.2
8835-003	7460	Manganese	<0.67	BQL	U	13.4	<0.59	BQL	U	11.9					<1.01	BQL	U	20.2
8835-003	7470	Mercury	<0.10	BQL	U	1.00	<0.11	BQL	U	1.00					<0.17	BQL	U	1.00
8835-003	7520	Nickel	<2.67	BQL	U	13.4	<2.38	BQL	U	11.9					<4.04	6.81		20.2
8835-003	7740	Selenium	<0.13	BQL	U	13.4	<0.12	BQL	U	11.9					<0.20	BQL	U	20.2
8835-003	7760	Silver	<1.34	BQL	U	13.4	<1.19	BQL	U	11.9					<2.02	BQL	U	20.2
8835-003	7840	Thallium	<13.4	BQL	U	13.4	<11.9	BQL	U	11.9					<20.2	BQL	U	20.2

COMPARATIVE FUELS RESULTS - METALS (mg/Kg)

Sample	Method	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
			Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-004	7040	Antimony	<6.67	BQL	U	13.3	<5.96	BQL	U	11.9					<10.1	BQL	U	20.2
8835-004	7060	Arsenic	<0.13	BQL	U	13.3	<0.12	BQL	U	11.9					<0.20	BQL	U	20.2
8835-004	7080	Barium	<13.3	BQL	U	13.3	<11.9	BQL	U	11.9					<20.2	BQL	U	20.2
8835-004	7090	Beryllium	<0.67	BQL	U	13.3	<0.60	BQL	U	11.9					<1.01	BQL	U	20.2
8835-004	7130	Cadmium	<0.67	BQL	U	13.3	<0.60	BQL	U	11.9					<1.01	BQL	U	20.2
8835-004	7190	Chromium	<1.33	BQL	U	13.3	<1.19	BQL	U	11.9					<2.02	BQL	U	20.2
8835-004	7200	Cobalt	<2.67	BQL	U	13.3	<2.38	BQL	U	11.9					<4.04	BQL	U	20.2
8835-004	7420	Lead	<6.67	BQL	U	13.3	<5.96	6.73		11.9					<10.1	54.2		20.2
8835-004	7460	Manganese	<0.66	BQL	U	13.3	<0.60	BQL	U	11.9					<1.01	BQL	U	20.2
8835-004	7470	Mercury	<0.10	BQL	U	1.00	<0.10	BQL	U	1.00					<0.14	BQL	U	1.00
8835-004	7520	Nickel	<2.67	BQL	U	13.3	<2.38	BQL	U	11.9					<4.04	5.86		20.2
8835-004	7740	Selenium	<0.13	BQL	U	13.3	<0.12	BQL	U	11.9					<0.20	BQL	U	20.2
8835-004	7760	Silver	<1.33	BQL	U	13.3	<1.19	BQL	U	11.9					<2.02	BQL	U	20.2
8835-004	7840	Thallium	<13.3	BQL	U	13.3	<11.9	BQL	U	11.9					<20.2	BQL	U	20.2
8835-005	7040	Antimony	<6.71	BQL	U	13.4	<5.94	BQL	U	11.9					<10.1	15.7		20.1
8835-005	7060	Arsenic	<0.13	BQL	U	13.4	<0.12	BQL	U	11.9					<0.20	BQL	U	20.1
8835-005	7080	Barium	<13.4	BQL	U	13.4	<11.9	BQL	U	11.9					<20.1	BQL	U	20.1
8835-005	7090	Beryllium	<0.67	BQL	U	13.4	<0.59	BQL	U	11.9					<1.01	BQL	U	20.1
8835-005	7130	Cadmium	<0.67	BQL	U	13.4	<0.59	BQL	U	11.9					<1.01	BQL	U	20.1
8835-005	7190	Chromium	<1.34	BQL	U	13.4	<1.19	BQL	U	11.9					<2.01	BQL	U	20.1
8835-005	7200	Cobalt	<2.68	BQL	U	13.4	<2.38	BQL	U	11.9					<4.02	BQL	U	20.1
8835-005	7420	Lead	<6.71	BQL	U	13.4	<5.94	10.1		11.9					<10.1	56.8		20.1
8835-005	7460	Manganese	<0.67	BQL	U	13.4	<0.59	BQL	U	11.9					<1.01	BQL	U	20.1
8835-005	7470	Mercury	<0.10	BQL	U	1.00	<0.09	BQL	U	1.00					<0.20	BQL	U	1.00
8835-005	7520	Nickel	<2.68	BQL	U	13.4	<2.38	BQL	U	11.9					<4.02	6.1		20.1
8835-005	7740	Selenium	<0.13	BQL	U	13.4	<0.12	BQL	U	11.9					<0.20	BQL	U	20.1
8835-005	7760	Silver	<1.34	BQL	U	13.4	<1.19	BQL	U	11.9					<2.01	BQL	U	20.1
8835-005	7840	Thallium	<13.4	BQL	U	13.4	<11.9	BQL	U	11.9					<20.1	BQL	U	20.1
8835-006	7040	Antimony	<7.05	BQL	U	14.1	<5.85	BQL	U	11.7					<10.2	BQL	U	20.4
8835-006	7060	Arsenic	<0.14	BQL	U	14.1	<0.12	BQL	U	11.7					<0.20	BQL	U	20.4
8835-006	7080	Barium	<14.1	BQL	U	14.1	<11.7	BQL	U	11.7					<20.4	BQL	U	20.4
8835-006	7090	Beryllium	<0.70	BQL	U	14.1	<0.58	BQL	U	11.7					<1.02	BQL	U	20.4
8835-006	7130	Cadmium	<0.70	BQL	U	14.1	<0.58	BQL	U	11.7					<1.02	BQL	U	20.4
8835-006	7190	Chromium	<1.41	BQL	U	14.1	<1.17	BQL	U	11.7					<2.04	BQL	U	20.4
8835-006	7200	Cobalt	<2.82	BQL	U	14.1	<2.34	BQL	U	11.7					<4.08	BQL	U	20.4
8835-006	7420	Lead	<7.05	BQL	U	14.1	<5.85	8.47		11.7					<10.2	35.4		20.4
8835-006	7460	Manganese	<0.70	BQL	U	14.1	<0.58	BQL	U	11.7					<1.02	BQL	U	20.4
8835-006	7470	Mercury	<0.10	BQL	U	1.00	<0.10	BQL	U	1.00					<0.25	BQL	U	1.00
8835-006	7520	Nickel	<2.82	BQL	U	14.1	<2.34	BQL	U	11.7					<4.08	50.2		20.4
8835-006	7740	Selenium	<0.14	BQL	U	14.1	<0.12	0.15		11.7					<0.20	BQL	U	20.4
8835-006	7760	Silver	<1.41	BQL	U	14.1	<1.17	BQL	U	11.7					<2.04	BQL	U	20.4

COMPARATIVE FUELS RESULTS - METALS (mg/Kg)

Sample	Method	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
			Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-006	7840	Thallium	<14.1	BQL	U	14.1	<11.7	BQL	U	11.7					<20.4	BQL	U	20.4
8835-007	7040	Antimony	<6.84	BQL	U	13.7	<5.88	BQL	U	11.8					<10.1	BQL	U	20.2
8835-007	7060	Arsenic	<0.14	BQL	U	13.7	<0.12	BQL	U	11.8					<0.20	BQL	U	20.2
8835-007	7080	Barium	<13.7	BQL	U	13.7	<11.8	BQL	U	11.8					<20.2	BQL	U	20.2
8835-007	7090	Beryllium	<0.68	BQL	U	13.7	<0.59	BQL	U	11.8					<1.01	BQL	U	20.2
8835-007	7130	Cadmium	<0.68	BQL	U	13.7	<0.59	BQL	U	11.8					<1.01	BQL	U	20.2
8835-007	7190	Chromium	<1.37	BQL	U	13.7	<1.18	BQL	U	11.8					<2.02	BQL	U	20.2
8835-007	7200	Cobalt	<2.74	BQL	U	13.7	<2.35	BQL	U	11.8					<4.04	BQL	U	20.2
8835-007	7420	Lead	<6.84	BQL	U	13.7	<5.88	11.9		11.8					<10.1	36.1		20.2
8835-007	7460	Manganese	<0.68	BQL	U	13.7	<0.59	BQL	U	11.8					<1.01	BQL	U	20.2
8835-007	7470	Mercury	<0.10	BQL	U	1.00	<0.10	BQL	U	1.00					<0.13	BQL	U	1.00
8835-007	7520	Nickel	<2.74	BQL	U	13.7	<2.35	BQL	U	11.8					<4.04	49.5		20.2
8835-007	7740	Selenium	<0.14	BQL	U	13.7	<0.12	BQL	U	11.8					<0.20	BQL	U	20.2
8835-007	7760	Silver	<1.37	BQL	U	13.7	<1.18	BQL	U	11.8					<2.02	BQL	U	20.2
8835-007	7840	Thallium	<13.7	BQL	U	13.7	<11.8	BQL	U	11.8					<20.2	BQL	U	20.2
8835-008	7040	Antimony	<6.92	BQL	U	13.9	<5.97	BQL	U	11.9								
8835-008	7060	Arsenic	<0.14	BQL	U	13.9	<0.12	BQL	U	11.9								
8835-008	7080	Barium	<13.8	BQL	U	13.9	<12.0	BQL	U	11.9								
8835-008	7090	Beryllium	<0.69	BQL	U	13.9	<0.60	BQL	U	11.9								
8835-008	7130	Cadmium	<0.69	BQL	U	13.9	<060	BQL	U	11.9								
8835-008	7190	Chromium	<1.38	BQL	U	13.9	<1.19	BQL	U	11.9								
8835-008	7200	Cobalt	<2.77	BQL	U	13.9	<2.39	BQL	U	11.9								
8835-008	7420	Lead	<6.92	BQL	U	13.9	<5.97	8.12		11.9								
8835-008	7460	Manganese	<0.69	BQL	U	13.9	<0.60	BQL	U	11.9								
8835-008	7470	Mercury	<0.10	BQL	U	1.00	<0.10	BQL	U	1.00								
8835-008	7520	Nickel	<2.77	BQL	U	13.9	<2.39	BQL	U	11.9								
8835-008	7740	Selenium	<0.14	BQL	U	13.9	<0.12	BQL	U	11.9								
8835-008	7760	Silver	<1.38	BQL	U	13.9	<1.19	BQL	U	11.9								
8835-008	7840	Thallium	<13.8	BQL	U	13.9	<12.0	BQL	U	11.9								
8835-009	7040	Antimony					<6.01	BQL	U	12.0								
8835-009	7060	Arsenic					<0.12	BQL	U	12.0								
8835-009	7080	Barium					<12.0	BQL	U	12.0								
8835-009	7090	Beryllium					<0.60	BQL	U	12.0								
8835-009	7130	Cadmium					<0.60	BQL	U	12.0								
8835-009	7190	Chromium					<1.20	BQL	U	12.0								
8835-009	7200	Cobalt					<2.40	BQL	U	12.0								
8835-009	7420	Lead					<6.01	7.6		12.0								
8835-009	7460	Manganese					<0.60	BQL	U	12.0								
8835-009	7470	Mercury					<0.11	BQL	U	1.00								
8835-009	7520	Nickel					<2.40	BQL	U	12.0								
8835-009	7740	Selenium					<0.12	BQL	U	12.0								

COMPARATIVE FUELS RESULTS - METALS (mg/Kg)

Sample	Method	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
			Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-009	7760	Silver					<1.20	BQL	U	12.0								
8835-009	7840	Thallium					<12.0	BQL	U	12.0								
8835-010	7040	Antimony					<5.98	BQL	U	12.0								
8835-010	7060	Arsenic					<0.12	BQL	U	12.0								
8835-010	7080	Barium					<12.0	BQL	U	12.0								
8835-010	7090	Beryllium					<0.60	BQL	U	12.0								
8835-010	7130	Cadmium					<0.60	BQL	U	12.0								
8835-010	7190	Chromium					<1.20	BQL	U	12.0								
8835-010	7200	Cobalt					<2.39	BQL	U	12.0								
8835-010	7420	Lead					<5.98	7.79		12.0								
8835-010	7460	Manganese					<0.60	BQL	U	12.0								
8835-010	7470	Mercury					<0.10	BQL	U	1.00								
8835-010	7520	Nickel					<2.39	BQL	U	12.0								
8835-010	7740	Selenium					<0.12	BQL	U	12.0								
8835-010	7760	Silver					<1.20	BQL	U	12.0								
8835-010	7840	Thallium					<12.0	BQL	U	12.0								
8835-011	7040	Antimony					<5.83	BQL	U	11.7								
8835-011	7060	Arsenic					<0.12	BQL	U	11.7								
8835-011	7080	Barium					<11.7	BQL	U	11.7								
8835-011	7090	Beryllium					<0.58	BQL	U	11.7								
8835-011	7130	Cadmium					<0.58	BQL	U	11.7								
8835-011	7190	Chromium					<1.17	BQL	U	11.7								
8835-011	7200	Cobalt					<2.33	BQL	U	11.7								
8835-011	7420	Lead					<5.83	9.87		11.7								
8835-011	7460	Manganese					<0.58	BQL	U	11.7								
8835-011	7470	Mercury					<0.10	BQL	U	1.00								
8835-011	7520	Nickel					<2.33	BQL	U	11.7								
8835-011	7740	Selenium					<0.12	BQL	U	11.7								
8835-011	7760	Silver					<1.17	BQL	U	11.7								
8835-011	7840	Thallium					<11.7	BQL	U	11.7								

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-001	1,2,4,5-Tetrachlorobenzene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	1,2,4-Trichlorobenzene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	1,2-Dichlorobenzene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	1,3,5-Trinitrobenzene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	1,3-Dichlorobenzene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	1,4-Dichlorobenzene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	1,4-Naphthoquinone	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	1-Naphthylamine	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	2,3,4,6-Tetrachlorophenol	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	2,4,5-Trichlorophenol	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	2,4,6-Trichlorophenol	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	2,4-Dichlorophenol	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	2,4-Dimethylphenol	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	2,4-Dinitrophenol	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	2,4-Dinitrotoluene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	2,6-Dichlorophenol	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	2,6-Dinitrotoluene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	2-Acetylaminofluorene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	2-Chloronaphthalene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	2-Chlorophenol	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	2-Methylphenol	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	2-Naphthylamine	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	2-Nitroaniline	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	2-Nitrophenol	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	2-Picoline	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	3,3'-Dichlorobenzidine	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	3-3'-Dimethylbenzidine	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	3-Methylcholanthrene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	4,6-Dinitro-2-methylphenol	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	4-Aminobiphenyl	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	4-Bromophenyl phenyl ether	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	4-Chloro-3-methylphenol	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	4-Chloroaniline	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	4-Methylphenol	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	4-Nitroaniline	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	4-Nitrophenol	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	5-Nitro-o-toluidine	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	7,12-Dimethylbenz[a]anthracene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	α,α-Dimethylphenethylamine	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Acetophenone	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Aniline	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Aramite	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Benzidine	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-001	Benzo[a]anthracene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Benzo[a]pyrene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Benzo[b]fluoranthene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Benzo[k]fluoranthene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Bis(2-chloroisopropyl)ether	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Butyl benzyl phthalate	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Chlorobenzilate	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Chrysene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Di-n-butyl phthalate	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Di-n-octyl phthalate	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Diallate	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Dibenzo[a,h]anthracene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Dibenz[a,j]acridine	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Diethyl phthalate	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Dimethoate	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Dimethyl phthalate	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Dinoseb	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Diphenylamine	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Disulfoton	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Ethyl methanesulfonate	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Famphur	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Fluoranthene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Fluorene	<270		U	26.7	<1200		U	117	<200	220		19.8	<99		U	9.9
8835-001	Hexachlorobenzene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Hexachlorobutadiene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Hexachlorocyclopentadiene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Hexachloroethane	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Hexachlorophene	<6700		U	26.7	<29000		U	117	<5000		U	19.8	<2500		U	9.9
8835-001	Hexachloropropene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Indeno(1,2,3-c,d)pyrene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Isodrin	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Isosafrole	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Kepone	<530		U	26.7	<2300		U	117	<400		U	19.8	<200		U	9.9
8835-001	Methapyrilene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Methyl parathion	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Methyl methanesulfonate	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	N-Nitroso-di-n-butylamine	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	N-Nitrosodi-n-propylamine	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	N-Nitrosodiethylamine	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	N-Nitrosomethylethylamine	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	N-Nitrosomorpholine	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	N-Nitrosopiperidine	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	N-Nitrosopyrrolidine	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	***Fuel = Gasoline***				***Fuel = No.2***				***Fuel = No.4***				***Fuel = No.6***			
		Q.L.	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**
8835-001	Naphthalene	<270	2500		26.7	<1200	2000		117	<200	660		19.8	<99	170		9.9
8835-001	Nitrobenzene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	O,O,O-Triethylphosphorothioate	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	o-Toluidine	<270		U	26.7	<1200		U	117	<200		U	19.8	<2000		U	9.9
8835-001	p-Dimethylaminoazobenzene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	p-Phenylenediamine	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Parathion	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Pentachlorobenzene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Pentachloronitrobenzene	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Pentachlorophenol	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Phenacetin	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Phenol	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Phorate	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Pronamide	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Pyridine	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Safrole	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Sulfotepp	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-001	Thionzin	<270		U	26.7	<1200		U	117	<200		U	19.8	<99		U	9.9
8835-002	1,2,4,5-Tetrachlorobenzene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	1,2,4-Trichlorobenzene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	1,2-Dichlorobenzene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	1,3,5-Trinitrobenzene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	1,3-Dichlorobenzene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	1,4-Dichlorobenzene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	1,4-Naphthoquinone	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	1-Naphthylamine	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	2,3,4,6-Tetrachlorophenol	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	2,4,5-Trichlorophenol	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	2,4,6-Trichlorophenol	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	2,4-Dichlorophenol	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	2,4-Dimethylphenol	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	2,4-Dinitrophenol	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	2,4-Dinitrotoluene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	2,6-Dichlorophenol	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	2,6-Dinitrotoluene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	2-Acetylaminofluorene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	2-Chloronaphthalene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	2-Chlorophenol	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	2-Methylphenol	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	2-Naphthylamine	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	2-Nitroaniline	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	2-Nitrophenol	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	2-Picoline	<270		U	26.6	<1200		U	117					<200		U	19.6

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	*Fuel = Gasoline*				*Fuel = No.2*				*Fuel = No.4*				*Fuel = No.6*			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-002	3,3'-Dichlorobenzidine	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	3-3'-Dimethylbenzidine	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	3-Methylcholanthrene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	4,6-Dinitro-2-methylphenol	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	4-Aminobiphenyl	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	4-Bromophenyl phenyl ether	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	4-Chloro-3-methylphenol	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	4-Chloroaniline	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	4-Methylphenol	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	4-Nitroaniline	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	4-Nitrophenol	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	5-Nitro-o-toluidine	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	7,12-Dimethylbenz[a]anthracene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	α,α-Dimethylphenethylamine	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Acetophenone	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Aniline	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Aramite	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Benzidine	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Benzo[a]anthracene	<270		U	26.6	<1200		U	117					<200	760		19.6
8835-002	Benzo[a]pyrene	<270		U	26.6	<1200		U	117					<200	450		19.6
8835-002	Benzo[b]fluoranthene	<270		U	26.6	<1200		U	117					<200	210		19.6
8835-002	Benzo[k]fluoranthene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Bis(2-chloroisopropyl)ether	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Butyl benzyl phthalate	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Chlorobenzilate	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Chrysene	<270		U	26.6	<1200		U	117					<200	700		19.6
8835-002	Di-n-butyl phthalate	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Di-n-octyl phthalate	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Diallate	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Dibenzo[a,h]anthracene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Dibenz[a,j]acridine	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Diethyl phthalate	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Dimethoate	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Dimethyl phthalate	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Dinoseb	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Diphenylamine	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Disulfoton	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Ethyl methanesulfonate	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Famphur	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Fluoranthene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Fluorene	<270		U	26.6	<1200		U	117					<200	220		19.6
8835-002	Hexachlorobenzene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Hexachlorobutadiene	<270		U	26.6	<1200		U	117					<200		U	19.6

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	*Fuel = Gasoline*				*Fuel = No.2*				*Fuel = No.4*				*Fuel = No.6*			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-002	Hexachlorocyclopentadiene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Hexachloroethane	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Hexachlorophene	<6600		U	26.6	<29000		U	117					<4900		U	19.6
8835-002	Hexachloropropene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Indeno(1,2,3-c,d)pyrene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Isodrin	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Isosafrole	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Kepone	<530		U	26.6	<2300		U	117					<390		U	19.6
8835-002	Methapyrilene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Methyl parathion	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Methyl methanesulfonate	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	N-Nitroso-di-n-butylamine	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	N-Nitrosodi-n-propylamine	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	N-Nitrosodiethylamine	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	N-Nitrosomethylethylamine	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	N-Nitrosomorpholine	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	N-Nitrosopiperidine	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	N-Nitrosopyrrolidine	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Naphthalene	<270	2600		26.6	<1200	2300		117					<200	550		19.6
8835-002	Nitrobenzene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	O,O,O-Triethylphosphorothioate	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	o-Toluidine	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	p-Dimethylaminoazobenzene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	p-Phenylenediamine	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Parathion	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Pentachlorobenzene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Pentachloronitrobenzene	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Pentachlorophenol	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Phenacetin	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Phenol	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Phorate	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Pronamide	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Pyridine	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Safrole	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Sulfotepp	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-002	Thionzin	<270		U	26.6	<1200		U	117					<200		U	19.6
8835-003	1,2,4,5-Tetrachlorobenzene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	1,2,4-Trichlorobenzene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	1,2-Dichlorobenzene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	1,3,5-Trinitrobenzene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	1,3-Dichlorobenzene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	1,4-Dichlorobenzene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	1,4-Naphthoquinone	<670		U	66.8	<590		U	59.4					<190		U	19.2

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	***Fuel = Gasoline***				***Fuel = No.2***				***Fuel = No.4***				***Fuel = No.6***			
		Q.L.	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**
8835-003	1-Naphthylamine	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	2,3,4,6-Tetrachlorophenol	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	2,4,5-Trichlorophenol	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	2,4,6-Trichlorophenol	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	2,4-Dichlorophenol	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	2,4-Dimethylphenol	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	2,4-Dinitrophenol	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	2,4-Dinitrotoluene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	2,6-Dichlorophenol	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	2,6-Dinitrotoluene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	2-Acetylaminofluorene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	2-Chloronaphthalene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	2-Chlorophenol	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	2-Methylphenol	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	2-Naphthylamine	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	2-Nitroaniline	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	2-Nitrophenol	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	2-Picoline	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	3,3'-Dichlorobenzidine	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	3-3'-Dimethylbenzidine	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	3-Methylcholanthrene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	4,6-Dinitro-2-methylphenol	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	4-Aminobiphenyl	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	4-Bromophenyl phenyl ether	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	4-Chloro-3-methylphenol	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	4-Chloroaniline	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	4-Methylphenol	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	4-Nitroaniline	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	4-Nitrophenol	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	5-Nitro-o-toluidine	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	7,12-Dimethylbenz[a]anthracene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	α,α-Dimethylphenethylamine	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Acetophenone	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Aniline	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Aramite	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Benzidine	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Benzo[a]anthracene	<670		U	66.8	<590		U	59.4					<190	660		19.2
8835-003	Benzo[a]pyrene	<670		U	66.8	<590		U	59.4					<190	450		19.2
8835-003	Benzo[b]fluoranthene	<670		U	66.8	<590		U	59.4					<190	220		19.2
8835-003	Benzo[k]fluoranthene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Bis(2-chloroisopropyl)ether	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Butyl benzyl phthalate	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Chlorobenzilate	<670		U	66.8	<590		U	59.4					<190		U	19.2

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	***Fuel = Gasoline***				***Fuel = No.2***				***Fuel = No.4***				***Fuel = No.6***			
		Q.L.	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**
8835-003	Chrysene	<670		U	66.8	<590		U	59.4					<190	740		19.2
8835-003	Di-n-butyl phthalate	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Di-n-octyl phthalate	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Diallate	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Dibenzo[a,h]anthracene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Dibenz[a,j]acridine	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Diethyl phthalate	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Dimethoate	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Dimethyl phthalate	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Dinoseb	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Diphenylamine	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Disulfoton	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Ethyl methanesulfonate	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Famphur	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Fluoranthene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Fluorene	<670		U	66.8	<590		U	59.4					<190	210		19.2
8835-003	Hexachlorobenzene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Hexachlorobutadiene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Hexachlorocyclopentadiene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Hexachloroethane	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Hexachlorophene	<17000		U	66.8	<15000		U	59.4					<4800		U	19.2
8835-003	Hexachloropropene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Indeno(1,2,3-c,d)pyrene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Isodrin	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Isosafrole	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Kepone	<1300		U	66.8	<1200		U	59.4					<380		U	19.2
8835-003	Methapyrilene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Methyl parathion	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Methyl methanesulfonate	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	N-Nitroso-di-n-butylamine	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	N-Nitrosodi-n-propylamine	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	N-Nitrosodiethylamine	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	N-Nitrosomethylethylamine	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	N-Nitrosomorpholine	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	N-Nitrosopiperidine	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	N-Nitrosopyrrolidine	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Naphthalene	<670	5400		66.8	<590	1300		59.4					<190	550		19.2
8835-003	Nitrobenzene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	O,O,O-Triethylphosphorothioate	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	o-Toluidine	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	p-Dimethylaminoazobenzene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	p-Phenylenediamine	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Parathion	<670		U	66.8	<590		U	59.4					<190		U	19.2

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-003	Pentachlorobenzene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Pentachloronitrobenzene	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Pentachlorophenol	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Phenacetin	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Phenol	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Phorate	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Pronamide	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Pyridine	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Safrole	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Sulfotepp	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-003	Thionzin	<670		U	66.8	<590		U	59.4					<190		U	19.2
8835-004	1,2,4,5-Tetrachlorobenzene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	1,2,4-Trichlorobenzene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	1,2-Dichlorobenzene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	1,3,5-Trinitrobenzene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	1,3-Dichlorobenzene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	1,4-Dichlorobenzene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	1,4-Naphthoquinone	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	1-Naphthylamine	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	2,3,4,6-Tetrachlorophenol	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	2,4,5-Trichlorophenol	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	2,4,6-Trichlorophenol	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	2,4-Dichlorophenol	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	2,4-Dimethylphenol	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	2,4-Dinitrophenol	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	2,4-Dinitrotoluene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	2,6-Dichlorophenol	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	2,6-Dinitrotoluene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	2-Acetylaminofluorene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	2-Chloronaphthalene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	2-Chlorophenol	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	2-Methylphenol	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	2-Naphthylamine	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	2-Nitroaniline	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	2-Nitrophenol	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	2-Picoline	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	3,3'-Dichlorobenzidine	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	3-3'-Dimethylbenzidine	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	3-Methylcholanthrene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	4,6-Dinitro-2-methylphenol	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	4-Aminobiphenyl	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	4-Bromophenyl phenyl ether	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	4-Chloro-3-methylphenol	<670		U	66.7	<600		U	59.6					<500		U	50.0

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	***Fuel = Gasoline***				***Fuel = No.2***				***Fuel = No.4***				***Fuel = No.6***			
		Q.L.	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**
8835-004	4-Chloroaniline	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	4-Methylphenol	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	4-Nitroaniline	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	4-Nitrophenol	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	5-Nitro-o-toluidine	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	7,12-Dimethylbenz[a]anthracene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	α,α-Dimethylphenethylamine	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Acetophenone	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Aniline	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Aramite	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Benzidine	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Benzo[a]anthracene	<670		U	66.7	<600		U	59.6					<500	1900		50.0
8835-004	Benzo[a]pyrene	<670		U	66.7	<600		U	59.6					<500	770		50.0
8835-004	Benzo[b]fluoranthene	<670		U	66.7	<600		U	59.6					<500	540		50.0
8835-004	Benzo[k]fluoranthene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Bis(2-chloroisopropyl)ether	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Butyl benzyl phthalate	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Chlorobenzilate	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Chrysene	<670		U	66.7	<600		U	59.6					<500	2700		50.0
8835-004	Di-n-butyl phthalate	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Di-n-octyl phthalate	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Diallate	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Dibenzo[a,h]anthracene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Dibenz[a,j]acridine	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Diethyl phthalate	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Dimethoate	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Dimethyl phthalate	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Dinoseb	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Diphenylamine	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Disulfoton	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Ethyl methanesulfonate	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Famphur	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Fluoranthene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Fluorene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Hexachlorobenzene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Hexachlorobutadiene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Hexachlorocyclopentadiene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Hexachloroethane	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Hexachlorophene	<17000		U	66.7	<15000		U	59.6					<12000		U	50.0
8835-004	Hexachloropropene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Indeno(1,2,3-c,d)pyrene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Isodrin	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Isosafrole	<670		U	66.7	<600		U	59.6					<500		U	50.0

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-004	Kepone	<1300		U	66.7	<1200		U	59.6					<1000		U	50.0
8835-004	Methapyrilene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Methyl parathion	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Methyl methanesulfonate	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	N-Nitroso-di-n-butylamine	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	N-Nitrosodi-n-propylamine	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	N-Nitrosodiethylamine	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	N-Nitrosomethylethylamine	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	N-Nitrosomorpholine	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	N-Nitrosopiperidine	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	N-Nitrosopyrrolidine	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Naphthalene	<670	6200		66.7	<600	1700		59.6					<500		U	50.0
8835-004	Nitrobenzene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	O,O,O-Triethylphosphorothioate	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	o-Toluidine	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	p-Dimethylaminoazobenzene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	p-Phenylenediamine	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Parathion	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Pentachlorobenzene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Pentachloronitrobenzene	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Pentachlorophenol	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Phenacetin	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Phenol	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Phorate	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Pronamide	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Pyridine	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Safrole	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Sulfotepp	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-004	Thionzin	<670		U	66.7	<600		U	59.6					<500		U	50.0
8835-005	1,2,4,5-Tetrachlorobenzene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	1,2,4-Trichlorobenzene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	1,2-Dichlorobenzene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	1,3,5-Trinitrobenzene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	1,3-Dichlorobenzene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	1,4-Dichlorobenzene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	1,4-Naphthoquinone	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	1-Naphthylamine	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	2,3,4,6-Tetrachlorophenol	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	2,4,5-Trichlorophenol	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	2,4,6-Trichlorophenol	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	2,4-Dichlorophenol	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	2,4-Dimethylphenol	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	2,4-Dinitrophenol	<130		U	13.4	<590		U	59.5					<200		U	19.8

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	***Fuel = Gasoline***				***Fuel = No.2***				***Fuel = No.4***				***Fuel = No.6***			
		Q.L.	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**
8835-005	2,4-Dinitrotoluene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	2,6-Dichlorophenol	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	2,6-Dinitrotoluene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	2-Acetylaminofluorene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	2-Chloronaphthalene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	2-Chlorophenol	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	2-Methylphenol	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	2-Naphthylamine	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	2-Nitroaniline	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	2-Nitrophenol	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	2-Picoline	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	3,3'-Dichlorobenzidine	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	3-3'-Dimethylbenzidine	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	3-Methylcholanthrene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	4,6-Dinitro-2-methylphenol	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	4-Aminobiphenyl	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	4-Bromophenyl phenyl ether	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	4-Chloro-3-methylphenol	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	4-Chloroaniline	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	4-Methylphenol	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	4-Nitroaniline	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	4-Nitrophenol	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	5-Nitro-o-toluidine	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	7,12-Dimethylbenz[a]anthracene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	α,α-Dimethylphenethylamine	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Acetophenone	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Aniline	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Aramite	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Benzidine	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Benzo[a]anthracene	<130		U	13.4	<590		U	59.5					<200	1600		19.8
8835-005	Benzo[a]pyrene	<130		U	13.4	<590		U	59.5					<200	960		19.8
8835-005	Benzo[b]fluoranthene	<130		U	13.4	<590		U	59.5					<200	670		19.8
8835-005	Benzo[k]fluoranthene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Bis(2-chloroisopropyl)ether	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Butyl benzyl phthalate	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Chlorobenzilate	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Chrysene	<130		U	13.4	<590		U	59.5					<200	2200		19.8
8835-005	Di-n-butyl phthalate	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Di-n-octyl phthalate	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Diallate	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Dibenzo[a,h]anthracene	<130		U	13.4	<590		U	59.5					<200	250		19.8
8835-005	Dibenz[a,j]acridine	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Diethyl phthalate	<130		U	13.4	<590		U	59.5					<200		U	19.8

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	***Fuel = Gasoline***				***Fuel = No.2***				***Fuel = No.4***				***Fuel = No.6***			
		Q.L.	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**
8835-005	Dimethoate	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Dimethyl phthalate	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Dinoseb	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Diphenylamine	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Disulfoton	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Ethyl methanesulfonate	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Famphur	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Fluoranthene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Fluorene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Hexachlorobenzene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Hexachlorobutadiene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Hexachlorocyclopentadiene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Hexachloroethane	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Hexachlorophene	<3400		U	13.4	<15000		U	59.5					<5000		U	19.8
8835-005	Hexachloropropene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Indeno(1,2,3-c,d)pyrene	<130		U	13.4	<590		U	59.5					<200	290		19.8
8835-005	Isodrin	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Isosafrole	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Kepone	<270		U	13.4	<1200		U	59.5					<400		U	19.8
8835-005	Methapyrilene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Methyl parathion	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Methyl methanesulfonate	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	N-Nitroso-di-n-butylamine	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	N-Nitrosodi-n-propylamine	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	N-Nitrosodiethylamine	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	N-Nitrosomethylethylamine	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	N-Nitrosomorpholine	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	N-Nitrosopiperidine	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	N-Nitrosopyrrolidine	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Naphthalene	<130	1300		13.4	<590	1700		59.5					<200	260		19.8
8835-005	Nitrobenzene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	O,O,O-Triethylphosphorothioate	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	o-Toluidine	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	p-Dimethylaminoazobenzene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	p-Phenylenediamine	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Parathion	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Pentachlorobenzene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Pentachloronitrobenzene	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Pentachlorophenol	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Phenacetin	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Phenol	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Phorate	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Pronamide	<130		U	13.4	<590		U	59.5					<200		U	19.8

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	*Fuel = Gasoline*				*Fuel = No.2*				*Fuel = No.4*				*Fuel = No.6*			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-005	Pyridine	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Safrole	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Sulfotepp	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-005	Thionzin	<130		U	13.4	<590		U	59.5					<200		U	19.8
8835-006	1,2,4,5-Tetrachlorobenzene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	1,2,4-Trichlorobenzene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	1,2-Dichlorobenzene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	1,3,5-Trinitrobenzene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	1,3-Dichlorobenzene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	1,4-Dichlorobenzene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	1,4-Naphthoquinone	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	1-Naphthylamine	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	2,3,4,6-Tetrachlorophenol	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	2,4,5-Trichlorophenol	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	2,4,6-Trichlorophenol	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	2,4-Dichlorophenol	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	2,4-Dimethylphenol	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	2,4-Dinitrophenol	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	2,4-Dinitrotoluene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	2,6-Dichlorophenol	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	2,6-Dinitrotoluene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	2-Acetylaminofluorene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	2-Chloronaphthalene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	2-Chlorophenol	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	2-Methylphenol	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	2-Naphthylamine	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	2-Nitroaniline	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	2-Nitrophenol	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	2-Picoline	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	3,3'-Dichlorobenzidine	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	3-3'-Dimethylbenzidine	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	3-Methylcholanthrene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	4,6-Dinitro-2-methylphenol	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	4-Aminobiphenyl	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	4-Bromophenyl phenyl ether	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	4-Chloro-3-methylphenol	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	4-Chloroaniline	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	4-Methylphenol	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	4-Nitroaniline	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	4-Nitrophenol	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	5-Nitro-o-toluidine	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	7,12-Dimethylbenz[a]anthracene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	α,α-Dimethylphenethylamine	<140		U	14.1	<290		U	29.3					<980		U	98.0

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-006	Acetophenone	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Aniline	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Aramite	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Benzidine	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Benzo[a]anthracene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Benzo[a]pyrene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Benzo[b]fluoranthene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Benzo[k]fluoranthene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Bis(2-chloroisopropyl)ether	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Butyl benzyl phthalate	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Chlorobenzilate	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Chrysene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Di-n-butyl phthalate	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Di-n-octyl phthalate	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Diallate	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Dibenzo[a,h]anthracene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Dibenz[a,j]acridine	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Diethyl phthalate	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Dimethoate	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Dimethyl phthalate	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Dinoseb	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Diphenylamine	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Disulfoton	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Ethyl methanesulfonate	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Famphur	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Fluoranthene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Fluorene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Hexachlorobenzene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Hexachlorobutadiene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Hexachlorocyclopentadiene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Hexachloroethane	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Hexachlorophene	<3500		U	14.1	<7300		U	29.3					<980		U	98.0
8835-006	Hexachloropropene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Indeno(1,2,3-c,d)pyrene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Isodrin	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Isosafrole	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Kepone	<280		U	14.1	<580		U	29.3					<2000		U	98.0
8835-006	Methapyrilene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Methyl parathion	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Methyl methanesulfonate	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	N-Nitroso-di-n-butylamine	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	N-Nitrosodi-n-propylamine	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	N-Nitrosodiethylamine	<140		U	14.1	<290		U	29.3					<980		U	98.0

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	*Fuel = Gasoline*				*Fuel = No.2*				*Fuel = No.4*				*Fuel = No.6*			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-006	N-Nitrosomethylethylamine	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	N-Nitrosomorpholine	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	N-Nitrosopiperidine	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	N-Nitrosopyrrolidine	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Naphthalene	<140	1100		14.1	<290		U	29.3					<980	1900		98.0
8835-006	Nitrobenzene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	O,O,O-Triethylphosphorothioate	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	o-Toluidine	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	p-Dimethylaminoazobenzene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	p-Phenylenediamine	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Parathion	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Pentachlorobenzene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Pentachloronitrobenzene	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Pentachlorophenol	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Phenacetin	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Phenol	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Phorate	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Pronamide	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Pyridine	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Safrole	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Sulfotepp	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-006	Thionzin	<140		U	14.1	<290		U	29.3					<980		U	98.0
8835-007	1,2,4,5-Tetrachlorobenzene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	1,2,4-Trichlorobenzene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	1,2-Dichlorobenzene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	1,3,5-Trinitrobenzene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	1,3-Dichlorobenzene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	1,4-Dichlorobenzene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	1,4-Naphthoquinone	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	1-Naphthylamine	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	2,3,4,6-Tetrachlorophenol	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	2,4,5-Trichlorophenol	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	2,4,6-Trichlorophenol	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	2,4-Dichlorophenol	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	2,4-Dimethylphenol	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	2,4-Dinitrophenol	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	2,4-Dinitrotoluene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	2,6-Dichlorophenol	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	2,6-Dinitrotoluene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	2-Acetylaminofluorene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	2-Chloronaphthalene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	2-Chlorophenol	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	2-Methylphenol	<270		U	27.4	<2400		U	235					<200		U	19.6

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-007	2-Naphthylamine	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	2-Nitroaniline	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	2-Nitrophenol	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	2-Picoline	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	3,3'-Dichlorobenzidine	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	3-3'-Dimethylbenzidine	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	3-Methylcholanthrene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	4,6-Dinitro-2-methylphenol	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	4-Aminobiphenyl	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	4-Bromophenyl phenyl ether	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	4-Chloro-3-methylphenol	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	4-Chloroaniline	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	4-Methylphenol	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	4-Nitroaniline	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	4-Nitrophenol	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	5-Nitro-o-toluidine	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	7,12-Dimethylbenz[a]anthracene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	α,α-Dimethylphenethylamine	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Acetophenone	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Aniline	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Aramite	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Benzidine	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Benzo[a]anthracene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Benzo[a]pyrene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Benzo[b]fluoranthene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Benzo[k]fluoranthene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Bis(2-chloroisopropyl)ether	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Butyl benzyl phthalate	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Chlorobenzilate	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Chrysene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Di-n-butyl phthalate	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Di-n-octyl phthalate	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Diallate	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Dibenzo[a,h]anthracene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Dibenz[a,j]acridine	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Diethyl phthalate	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Dimethoate	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Dimethyl phthalate	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Dinoseb	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Diphenylamine	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Disulfoton	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Ethyl methanesulfonate	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Famphur	<270		U	27.4	<2400		U	235					<200		U	19.6

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-007	Fluoranthene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Fluorene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Hexachlorobenzene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Hexachlorobutadiene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Hexachlorocyclopentadiene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Hexachloroethane	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Hexachlorophene	<6800		U	27.4	<59000		U	235					<4900		U	19.6
8835-007	Hexachloropropene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Indeno(1,2,3-c,d)pyrene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Isodrin	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Isosafrole	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Kepone	<550		U	27.4	<4700		U	235					<390		U	19.6
8835-007	Methapyrilene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Methyl parathion	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Methyl methanesulfonate	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	N-Nitroso-di-n-butylamine	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	N-Nitrosodi-n-propylamine	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	N-Nitrosodiethylamine	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	N-Nitrosomethylethylamine	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	N-Nitrosomorpholine	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	N-Nitrosopiperidine	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	N-Nitrosopyrrolidine	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Naphthalene	<270	2300		27.4	<2400	3500		235					<200	690		19.6
8835-007	Nitrobenzene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	O,O,O-Triethylphosphorothioate	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	o-Toluidine	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	p-Dimethylaminoazobenzene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	p-Phenylenediamine	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Parathion	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Pentachlorobenzene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Pentachloronitrobenzene	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Pentachlorophenol	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Phenacetin	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Phenol	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Phorate	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Pronamide	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Pyridine	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Safrole	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Sulfotepp	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-007	Thionzin	<270		U	27.4	<2400		U	235					<200		U	19.6
8835-008	1,2,4,5-Tetrachlorobenzene	<280		U	27.7	<600		U	59.7								
8835-008	1,2,4-Trichlorobenzene	<280		U	27.7	<600		U	59.7								
8835-008	1,2-Dichlorobenzene	<280		U	27.7	<600		U	59.7								

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-008	1,3,5-Trinitrobenzene	<280		U	27.7	<600		U	59.7								
8835-008	1,3-Dichlorobenzene	<280		U	27.7	<600		U	59.7								
8835-008	1,4-Dichlorobenzene	<280		U	27.7	<600		U	59.7								
8835-008	1,4-Naphthoquinone	<280		U	27.7	<600		U	59.7								
8835-008	1-Naphthylamine	<280		U	27.7	<600		U	59.7								
8835-008	2,3,4,6-Tetrachlorophenol	<280		U	27.7	<600		U	59.7								
8835-008	2,4,5-Trichlorophenol	<280		U	27.7	<600		U	59.7								
8835-008	2,4,6-Trichlorophenol	<280		U	27.7	<600		U	59.7								
8835-008	2,4-Dichlorophenol	<280		U	27.7	<600		U	59.7								
8835-008	2,4-Dimethylphenol	<280		U	27.7	<600		U	59.7								
8835-008	2,4-Dinitrophenol	<280		U	27.7	<600		U	59.7								
8835-008	2,4-Dinitrotoluene	<280		U	27.7	<600		U	59.7								
8835-008	2,6-Dichlorophenol	<280		U	27.7	<600		U	59.7								
8835-008	2,6-Dinitrotoluene	<280		U	27.7	<600		U	59.7								
8835-008	2-Acetylaminofluorene	<280		U	27.7	<600		U	59.7								
8835-008	2-Chloronaphthalene	<280		U	27.7	<600		U	59.7								
8835-008	2-Chlorophenol	<280		U	27.7	<600		U	59.7								
8835-008	2-Methylphenol	<280		U	27.7	<600		U	59.7								
8835-008	2-Naphthylamine	<280		U	27.7	<600		U	59.7								
8835-008	2-Nitroaniline	<280		U	27.7	<600		U	59.7								
8835-008	2-Nitrophenol	<280		U	27.7	<600		U	59.7								
8835-008	2-Picoline	<280		U	27.7	<600		U	59.7								
8835-008	3,3'-Dichlorobenzidine	<280		U	27.7	<600		U	59.7								
8835-008	3-3'-Dimethylbenzidine	<280		U	27.7	<600		U	59.7								
8835-008	3-Methylcholanthrene	<280		U	27.7	<600		U	59.7								
8835-008	4,6-Dinitro-2-methylphenol	<280		U	27.7	<600		U	59.7								
8835-008	4-Aminobiphenyl	<280		U	27.7	<600		U	59.7								
8835-008	4-Bromophenyl phenyl ether	<280		U	27.7	<600		U	59.7								
8835-008	4-Chloro-3-methylphenol	<280		U	27.7	<600		U	59.7								
8835-008	4-Chloroaniline	<280		U	27.7	<600		U	59.7								
8835-008	4-Methylphenol	<280		U	27.7	<600		U	59.7								
8835-008	4-Nitroaniline	<280		U	27.7	<600		U	59.7								
8835-008	4-Nitrophenol	<280		U	27.7	<600		U	59.7								
8835-008	5-Nitro-o-toluidine	<280		U	27.7	<600		U	59.7								
8835-008	7,12-Dimethylbenz[a]anthracene	<280		U	27.7	<600		U	59.7								
8835-008	α,α-Dimethylphenethylamine	<280		U	27.7	<600		U	59.7								
8835-008	Acetophenone	<280		U	27.7	<600		U	59.7								
8835-008	Aniline	<280		U	27.7	<600		U	59.7								
8835-008	Aramite	<280		U	27.7	<600		U	59.7								
8835-008	Benzidine	<280		U	27.7	<600		U	59.7								
8835-008	Benzo[a]anthracene	<280		U	27.7	<600		U	59.7								
8835-008	Benzo[a]pyrene	<280		U	27.7	<600		U	59.7								
8835-008	Benzo[b]fluoranthene	<280		U	27.7	<600		U	59.7								

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-008	Benzo[k]fluoranthene	<280		U	27.7	<600		U	59.7								
8835-008	Bis(2-chloroisopropyl)ether	<280		U	27.7	<600		U	59.7								
8835-008	Butyl benzyl phthalate	<280		U	27.7	<600		U	59.7								
8835-008	Chlorobenzilate	<280		U	27.7	<600		U	59.7								
8835-008	Chrysene	<280		U	27.7	<600		U	59.7								
8835-008	Di-n-butyl phthalate	<280		U	27.7	<600		U	59.7								
8835-008	Di-n-octyl phthalate	<280		U	27.7	<600		U	59.7								
8835-008	Diallate	<280		U	27.7	<600		U	59.7								
8835-008	Dibenzo[a,h]anthracene	<280		U	27.7	<600		U	59.7								
8835-008	Dibenz[a,j]acridine	<280		U	27.7	<600		U	59.7								
8835-008	Diethyl phthalate	<280		U	27.7	<600		U	59.7								
8835-008	Dimethoate	<280		U	27.7	<600		U	59.7								
8835-008	Dimethyl phthalate	<280		U	27.7	<600		U	59.7								
8835-008	Dinoseb	<280		U	27.7	<600		U	59.7								
8835-008	Diphenylamine	<280		U	27.7	<600		U	59.7								
8835-008	Disulfoton	<280		U	27.7	<600		U	59.7								
8835-008	Ethyl methanesulfonate	<280		U	27.7	<600		U	59.7								
8835-008	Famphur	<280		U	27.7	<600		U	59.7								
8835-008	Fluoranthene	<280		U	27.7	<600		U	59.7								
8835-008	Fluorene	<280		U	27.7	<600		U	59.7								
8835-008	Hexachlorobenzene	<280		U	27.7	<600		U	59.7								
8835-008	Hexachlorobutadiene	<280		U	27.7	<600		U	59.7								
8835-008	Hexachlorocyclopentadiene	<280		U	27.7	<600		U	59.7								
8835-008	Hexachloroethane	<280		U	27.7	<600		U	59.7								
8835-008	Hexachlorophene	<6900		U	27.7	<15000		U	59.7								
8835-008	Hexachloropropene	<280		U	27.7	<600		U	59.7								
8835-008	Indeno(1,2,3-c,d)pyrene	<280		U	27.7	<600		U	59.7								
8835-008	Isodrin	<280		U	27.7	<600		U	59.7								
8835-008	Isosafrole	<280		U	27.7	<600		U	59.7								
8835-008	Kepone	<550		U	27.7	<1200		U	59.7								
8835-008	Methapyrilene	<280		U	27.7	<600		U	59.7								
8835-008	Methyl parathion	<280		U	27.7	<600		U	59.7								
8835-008	Methyl methanesulfonate	<280		U	27.7	<600		U	59.7								
8835-008	N-Nitroso-di-n-butylamine	<280		U	27.7	<600		U	59.7								
8835-008	N-Nitrosodi-n-propylamine	<280		U	27.7	<600		U	59.7								
8835-008	N-Nitrosodiethylamine	<280		U	27.7	<600		U	59.7								
8835-008	N-Nitrosomethylethylamine	<280		U	27.7	<600		U	59.7								
8835-008	N-Nitrosomorpholine	<280		U	27.7	<600		U	59.7								
8835-008	N-Nitrosopiperidine	<280		U	27.7	<600		U	59.7								
8835-008	N-Nitrosopyrrolidine	<280		U	27.7	<600		U	59.7								
8835-008	Naphthalene	<280	2100		27.7	<600	1800		59.7								
8835-008	Nitrobenzene	<280		U	27.7	<600		U	59.7								
8835-008	O,O,O-Triethylphosphorothioate	<280		U	27.7	<600		U	59.7								

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant- itation	Code	D.F.	Q.L.	Quant- itation	Code	D.F.	Q.L.	Quant- itation	Code	D.F.	Q.L.	Quant- itation	Code	D.F.
8835-008	o-Toluidine	<280		U	27.7	<600		U	59.7								
8835-008	p-Dimethylaminoazobenzene	<280		U	27.7	<600		U	59.7								
8835-008	p-Phenylenediamine	<280		U	27.7	<600		U	59.7								
8835-008	Parathion	<280		U	27.7	<600		U	59.7								
8835-008	Pentachlorobenzene	<280		U	27.7	<600		U	59.7								
8835-008	Pentachloronitrobenzene	<280		U	27.7	<600		U	59.7								
8835-008	Pentachlorophenol	<280		U	27.7	<600		U	59.7								
8835-008	Phenacetin	<280		U	27.7	<600		U	59.7								
8835-008	Phenol	<280		U	27.7	<600		U	59.7								
8835-008	Phorate	<280		U	27.7	<600		U	59.7								
8835-008	Pronamide	<280		U	27.7	<600		U	59.7								
8835-008	Pyridine	<280		U	27.7	<600		U	59.7								
8835-008	Safrole	<280		U	27.7	<600		U	59.7								
8835-008	Sulfotepp	<280		U	27.7	<600		U	59.7								
8835-008	Thionzin	<280		U	27.7	<600		U	59.7								
8835-009	1,2,4,5-Tetrachlorobenzene					<600		U	60.1								
8835-009	1,2,4-Trichlorobenzene					<600		U	60.1								
8835-009	1,2-Dichlorobenzene					<600		U	60.1								
8835-009	1,3,5-Trinitrobenzene					<600		U	60.1								
8835-009	1,3-Dichlorobenzene					<600		U	60.1								
8835-009	1,4-Dichlorobenzene					<600		U	60.1								
8835-009	1,4-Naphthoquinone					<600		U	60.1								
8835-009	1-Naphthylamine					<600		U	60.1								
8835-009	2,3,4,6-Tetrachlorophenol					<600		U	60.1								
8835-009	2,4,5-Trichlorophenol					<600		U	60.1								
8835-009	2,4,6-Trichlorophenol					<600		U	60.1								
8835-009	2,4-Dichlorophenol					<600		U	60.1								
8835-009	2,4-Dimethylphenol					<600		U	60.1								
8835-009	2,4-Dinitrophenol					<600		U	60.1								
8835-009	2,4-Dinitrotoluene					<600		U	60.1								
8835-009	2,6-Dichlorophenol					<600		U	60.1								
8835-009	2,6-Dinitrotoluene					<600		U	60.1								
8835-009	2-Acetylaminofluorene					<600		U	60.1								
8835-009	2-Chloronaphthalene					<600		U	60.1								
8835-009	2-Chlorophenol					<600		U	60.1								
8835-009	2-Methylphenol					<600		U	60.1								
8835-009	2-Naphthylamine					<600		U	60.1								
8835-009	2-Nitroaniline					<600		U	60.1								
8835-009	2-Nitrophenol					<600		U	60.1								
8835-009	2-Picoline					<600		U	60.1								
8835-009	3,3'-Dichlorobenzidine					<600		U	60.1								
8835-009	3-3'-Dimethylbenzidine					<600		U	60.1								
8835-009	3-Methylcholanthrene					<600		U	60.1								

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-009	4,6-Dinitro-2-methylphenol					<600		U	60.1								
8835-009	4-Aminobiphenyl					<600		U	60.1								
8835-009	4-Bromophenyl phenyl ether					<600		U	60.1								
8835-009	4-Chloro-3-methylphenol					<600		U	60.1								
8835-009	4-Chloroaniline					<600		U	60.1								
8835-009	4-Methylphenol					<600		U	60.1								
8835-009	4-Nitroaniline					<600		U	60.1								
8835-009	4-Nitrophenol					<600		U	60.1								
8835-009	5-Nitro-o-toluidine					<600		U	60.1								
8835-009	7,12-Dimethylbenz[a]anthracene					<600		U	60.1								
8835-009	α,α-Dimethylphenethylamine					<600		U	60.1								
8835-009	Acetophenone					<600		U	60.1								
8835-009	Aniline					<600		U	60.1								
8835-009	Aramite					<600		U	60.1								
8835-009	Benzidine					<600		U	60.1								
8835-009	Benzo[a]anthracene					<600		U	60.1								
8835-009	Benzo[a]pyrene					<600		U	60.1								
8835-009	Benzo[b]fluoranthene					<600		U	60.1								
8835-009	Benzo[k]fluoranthene					<600		U	60.1								
8835-009	Bis(2-chloroisopropyl)ether					<600		U	60.1								
8835-009	Butyl benzyl phthalate					<600		U	60.1								
8835-009	Chlorobenzilate					<600		U	60.1								
8835-009	Chrysene					<600		U	60.1								
8835-009	Di-n-butyl phthalate					<600		U	60.1								
8835-009	Di-n-octyl phthalate					<600		U	60.1								
8835-009	Diallate					<600		U	60.1								
8835-009	Dibenzo[a,h]anthracene					<600		U	60.1								
8835-009	Dibenz[a,j]acridine					<600		U	60.1								
8835-009	Diethyl phthalate					<600		U	60.1								
8835-009	Dimethoate					<600		U	60.1								
8835-009	Dimethyl phthalate					<600		U	60.1								
8835-009	Dinoseb					<600		U	60.1								
8835-009	Diphenylamine					<600		U	60.1								
8835-009	Disulfoton					<600		U	60.1								
8835-009	Ethyl methanesulfonate					<600		U	60.1								
8835-009	Famphur					<600		U	60.1								
8835-009	Fluoranthene					<600		U	60.1								
8835-009	Fluorene					<600		U	60.1								
8835-009	Hexachlorobenzene					<600		U	60.1								
8835-009	Hexachlorobutadiene					<600		U	60.1								
8835-009	Hexachlorocyclopentadiene					<600		U	60.1								
8835-009	Hexachloroethane					<600		U	60.1								
8835-009	Hexachlorophene					<15000		U	60.1								

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-009	Hexachloropropene					<600		U	60.1								
8835-009	Indeno(1,2,3-c,d)pyrene					<600		U	60.1								
8835-009	Isodrin					<600		U	60.1								
8835-009	Isosafrole					<600		U	60.1								
8835-009	Kepone					<1200		U	60.1								
8835-009	Methapyrilene					<600		U	60.1								
8835-009	Methyl parathion					<600		U	60.1								
8835-009	Methyl methanesulfonate					<600		U	60.1								
8835-009	N-Nitroso-di-n-butylamine					<600		U	60.1								
8835-009	N-Nitrosodi-n-propylamine					<600		U	60.1								
8835-009	N-Nitrosodiethylamine					<600		U	60.1								
8835-009	N-Nitrosomethylethylamine					<600		U	60.1								
8835-009	N-Nitrosomorpholine					<600		U	60.1								
8835-009	N-Nitrosopiperidine					<600		U	60.1								
8835-009	N-Nitrosopyrrolidine					<600		U	60.1								
8835-009	Naphthalene					<600	650		60.1								
8835-009	Nitrobenzene					<600		U	60.1								
8835-009	O,O,O-Triethylphosphorothioate					<600		U	60.1								
8835-009	o-Toluidine					<600		U	60.1								
8835-009	p-Dimethylaminoazobenzene					<600		U	60.1								
8835-009	p-Phenylenediamine					<600		U	60.1								
8835-009	Parathion					<600		U	60.1								
8835-009	Pentachlorobenzene					<600		U	60.1								
8835-009	Pentachloronitrobenzene					<600		U	60.1								
8835-009	Pentachlorophenol					<600		U	60.1								
8835-009	Phenacetin					<600		U	60.1								
8835-009	Phenol					<600		U	60.1								
8835-009	Phorate					<600		U	60.1								
8835-009	Pronamide					<600		U	60.1								
8835-009	Pyridine					<600		U	60.1								
8835-009	Safrole					<600		U	60.1								
8835-009	Sulfotepp					<600		U	60.1								
8835-009	Thionzin					<600		U	60.1								
8835-010	1,2,4,5-Tetrachlorobenzene					<600		U	59.8								
8835-010	1,2,4-Trichlorobenzene					<600		U	59.8								
8835-010	1,2-Dichlorobenzene					<600		U	59.8								
8835-010	1,3,5-Trinitrobenzene					<600		U	59.8								
8835-010	1,3-Dichlorobenzene					<600		U	59.8								
8835-010	1,4-Dichlorobenzene					<600		U	59.8								
8835-010	1,4-Naphthoquinone					<600		U	59.8								
8835-010	1-Naphthylamine					<600		U	59.8								
8835-010	2,3,4,6-Tetrachlorophenol					<600		U	59.8								
8835-010	2,4,5-Trichlorophenol					<600		U	59.8								

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-010	2,4,6-Trichlorophenol					<600		U	59.8								
8835-010	2,4-Dichlorophenol					<600		U	59.8								
8835-010	2,4-Dimethylphenol					<600		U	59.8								
8835-010	2,4-Dinitrophenol					<600		U	59.8								
8835-010	2,4-Dinitrotoluene					<600		U	59.8								
8835-010	2,6-Dichlorophenol					<600		U	59.8								
8835-010	2,6-Dinitrotoluene					<600		U	59.8								
8835-010	2-Acetylaminofluorene					<600		U	59.8								
8835-010	2-Chloronaphthalene					<600		U	59.8								
8835-010	2-Chlorophenol					<600		U	59.8								
8835-010	2-Methylphenol					<600		U	59.8								
8835-010	2-Naphthylamine					<600		U	59.8								
8835-010	2-Nitroaniline					<600		U	59.8								
8835-010	2-Nitrophenol					<600		U	59.8								
8835-010	2-Picoline					<600		U	59.8								
8835-010	3,3'-Dichlorobenzidine					<600		U	59.8								
8835-010	3-3'-Dimethylbenzidine					<600		U	59.8								
8835-010	3-Methylcholanthrene					<600		U	59.8								
8835-010	4,6-Dinitro-2-methylphenol					<600		U	59.8								
8835-010	4-Aminobiphenyl					<600		U	59.8								
8835-010	4-Bromophenyl phenyl ether					<600		U	59.8								
8835-010	4-Chloro-3-methylphenol					<600		U	59.8								
8835-010	4-Chloroaniline					<600		U	59.8								
8835-010	4-Methylphenol					<600		U	59.8								
8835-010	4-Nitroaniline					<600		U	59.8								
8835-010	4-Nitrophenol					<600		U	59.8								
8835-010	5-Nitro-o-toluidine					<600		U	59.8								
8835-010	7,12-Dimethylbenz[a]anthracene					<600		U	59.8								
8835-010	α,α-Dimethylphenethylamine					<600		U	59.8								
8835-010	Acetophenone					<600		U	59.8								
8835-010	Aniline					<600		U	59.8								
8835-010	Aramite					<600		U	59.8								
8835-010	Benzidine					<600		U	59.8								
8835-010	Benzo[a]anthracene					<600		U	59.8								
8835-010	Benzo[a]pyrene					<600		U	59.8								
8835-010	Benzo[b]fluoranthene					<600		U	59.8								
8835-010	Benzo[k]fluoranthene					<600		U	59.8								
8835-010	Bis(2-chloroisopropyl)ether					<600		U	59.8								
8835-010	Butyl benzyl phthalate					<600		U	59.8								
8835-010	Chlorobenzilate					<600		U	59.8								
8835-010	Chrysene					<600		U	59.8								
8835-010	Di-n-butyl phthalate					<600		U	59.8								
8835-010	Di-n-octyl phthalate					<600		U	59.8								

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-010	Diallate					<600		U	59.8								
8835-010	Dibenzo[a,h]anthracene					<600		U	59.8								
8835-010	Dibenz[a,j]acridine					<600		U	59.8								
8835-010	Diethyl phthalate					<600		U	59.8								
8835-010	Dimethoate					<600		U	59.8								
8835-010	Dimethyl phthalate					<600		U	59.8								
8835-010	Dinoseb					<600		U	59.8								
8835-010	Diphenylamine					<600		U	59.8								
8835-010	Disulfoton					<600		U	59.8								
8835-010	Ethyl methanesulfonate					<600		U	59.8								
8835-010	Famphur					<600		U	59.8								
8835-010	Fluoranthene					<600		U	59.8								
8835-010	Fluorene					<600		U	59.8								
8835-010	Hexachlorobenzene					<600		U	59.8								
8835-010	Hexachlorobutadiene					<600		U	59.8								
8835-010	Hexachlorocyclopentadiene					<600		U	59.8								
8835-010	Hexachloroethane					<600		U	59.8								
8835-010	Hexachlorophene					<15000		U	59.8								
8835-010	Hexachloropropene					<600		U	59.8								
8835-010	Indeno(1,2,3-c,d)pyrene					<600		U	59.8								
8835-010	Isodrin					<600		U	59.8								
8835-010	Isosafrole					<600		U	59.8								
8835-010	Kepone					<1200		U	59.8								
8835-010	Methapyrilene					<600		U	59.8								
8835-010	Methyl parathion					<600		U	59.8								
8835-010	Methyl methanesulfonate					<600		U	59.8								
8835-010	N-Nitroso-di-n-butylamine					<600		U	59.8								
8835-010	N-Nitrosodi-n-propylamine					<600		U	59.8								
8835-010	N-Nitrosodiethylamine					<600		U	59.8								
8835-010	N-Nitrosomethylethylamine					<600		U	59.8								
8835-010	N-Nitrosomorpholine					<600		U	59.8								
8835-010	N-Nitrosopiperidine					<600		U	59.8								
8835-010	N-Nitrosopyrrolidine					<600		U	59.8								
8835-010	Naphthalene					<600	710		59.8								
8835-010	Nitrobenzene					<600		U	59.8								
8835-010	O,O,O-Triethylphosphorothioate					<600		U	59.8								
8835-010	o-Toluidine					<600		U	59.8								
8835-010	p-Dimethylaminoazobenzene					<600		U	59.8								
8835-010	p-Phenylenediamine					<600		U	59.8								
8835-010	Parathion					<600		U	59.8								
8835-010	Pentachlorobenzene					<600		U	59.8								
8835-010	Pentachloronitrobenzene					<600		U	59.8								
8835-010	Pentachlorophenol					<600		U	59.8								

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-010	Phenacetin					<600		U	59.8								
8835-010	Phenol					<600		U	59.8								
8835-010	Phorate					<600		U	59.8								
8835-010	Pronamide					<600		U	59.8								
8835-010	Pyridine					<600		U	59.8								
8835-010	Safrole					<600		U	59.8								
8835-010	Sulfotepp					<600		U	59.8								
8835-010	Thionzin					<600		U	59.8								
8835-011	1,2,4,5-Tetrachlorobenzene					<580		U	58.3								
8835-011	1,2,4-Trichlorobenzene					<580		U	58.3								
8835-011	1,2-Dichlorobenzene					<580		U	58.3								
8835-011	1,3,5-Trinitrobenzene					<580		U	58.3								
8835-011	1,3-Dichlorobenzene					<580		U	58.3								
8835-011	1,4-Dichlorobenzene					<580		U	58.3								
8835-011	1,4-Naphthoquinone					<580		U	58.3								
8835-011	1-Naphthylamine					<580		U	58.3								
8835-011	2,3,4,6-Tetrachlorophenol					<580		U	58.3								
8835-011	2,4,5-Trichlorophenol					<580		U	58.3								
8835-011	2,4,6-Trichlorophenol					<580		U	58.3								
8835-011	2,4-Dichlorophenol					<580		U	58.3								
8835-011	2,4-Dimethylphenol					<580		U	58.3								
8835-011	2,4-Dinitrophenol					<580		U	58.3								
8835-011	2,4-Dinitrotoluene					<580		U	58.3								
8835-011	2,6-Dichlorophenol					<580		U	58.3								
8835-011	2,6-Dinitrotoluene					<580		U	58.3								
8835-011	2-Acetylaminofluorene					<580		U	58.3								
8835-011	2-Chloronaphthalene					<580		U	58.3								
8835-011	2-Chlorophenol					<580		U	58.3								
8835-011	2-Methylphenol					<580		U	58.3								
8835-011	2-Naphthylamine					<580		U	58.3								
8835-011	2-Nitroaniline					<580		U	58.3								
8835-011	2-Nitrophenol					<580		U	58.3								
8835-011	2-Picoline					<580		U	58.3								
8835-011	3,3'-Dichlorobenzidine					<580		U	58.3								
8835-011	3-3'-Dimethylbenzidine					<580		U	58.3								
8835-011	3-Methylcholanthrene					<580		U	58.3								
8835-011	4,6-Dinitro-2-methylphenol					<580		U	58.3								
8835-011	4-Aminobiphenyl					<580		U	58.3								
8835-011	4-Bromophenyl phenyl ether					<580		U	58.3								
8835-011	4-Chloro-3-methylphenol					<580		U	58.3								
8835-011	4-Chloroaniline					<580		U	58.3								
8835-011	4-Methylphenol					<580		U	58.3								
8835-011	4-Nitroaniline					<580		U	58.3								

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-011	4-Nitrophenol					<580		U	58.3								
8835-011	5-Nitro-o-toluidine					<580		U	58.3								
8835-011	7,12-Dimethylbenz[a]anthracene					<580		U	58.3								
8835-011	α,α-Dimethylphenethylamine					<580		U	58.3								
8835-011	Acetophenone					<580		U	58.3								
8835-011	Aniline					<580		U	58.3								
8835-011	Aramite					<580		U	58.3								
8835-011	Benzidine					<580		U	58.3								
8835-011	Benzo[a]anthracene					<580		U	58.3								
8835-011	Benzo[a]pyrene					<580		U	58.3								
8835-011	Benzo[b]fluoranthene					<580		U	58.3								
8835-011	Benzo[k]fluoranthene					<580		U	58.3								
8835-011	Bis(2-chloroisopropyl)ether					<580		U	58.3								
8835-011	Butyl benzyl phthalate					<580		U	58.3								
8835-011	Chlorobenzilate					<580		U	58.3								
8835-011	Chrysene					<580		U	58.3								
8835-011	Di-n-butyl phthalate					<580		U	58.3								
8835-011	Di-n-octyl phthalate					<580		U	58.3								
8835-011	Diallate					<580		U	58.3								
8835-011	Dibenzo[a,h]anthracene					<580		U	58.3								
8835-011	Dibenz[a,j]acridine					<580		U	58.3								
8835-011	Diethyl phthalate					<580		U	58.3								
8835-011	Dimethoate					<580		U	58.3								
8835-011	Dimethyl phthalate					<580		U	58.3								
8835-011	Dinoseb					<580		U	58.3								
8835-011	Diphenylamine					<580		U	58.3								
8835-011	Disulfoton					<580		U	58.3								
8835-011	Ethyl methanesulfonate					<580		U	58.3								
8835-011	Famphur					<580		U	58.3								
8835-011	Fluoranthene					<580		U	58.3								
8835-011	Fluorene					<580		U	58.3								
8835-011	Hexachlorobenzene					<580		U	58.3								
8835-011	Hexachlorobutadiene					<580		U	58.3								
8835-011	Hexachlorocyclopentadiene					<580		U	58.3								
8835-011	Hexachloroethane					<580		U	58.3								
8835-011	Hexachlorophene					<14000		U	58.3								
8835-011	Hexachloropropene					<580		U	58.3								
8835-011	Indeno(1,2,3-c,d)pyrene					<580		U	58.3								
8835-011	Isodrin					<580		U	58.3								
8835-011	Isosafrole					<580		U	58.3								
8835-011	Kepone					<1200		U	58.3								
8835-011	Methapyrilene					<580		U	58.3								
8835-011	Methyl parathion					<580		U	58.3								

COMPARABLE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-011	Methyl methanesulfonate					<580		U	58.3								
8835-011	N-Nitroso-di-n-butylamine					<580		U	58.3								
8835-011	N-Nitrosodi-n-propylamine					<580		U	58.3								
8835-011	N-Nitrosodiethylamine					<580		U	58.3								
8835-011	N-Nitrosomethylethylamine					<580		U	58.3								
8835-011	N-Nitrosomorpholine					<580		U	58.3								
8835-011	N-Nitrosopiperidine					<580		U	58.3								
8835-011	N-Nitrosopyrrolidine					<580		U	58.3								
8835-011	Naphthalene					<580	810		58.3								
8835-011	Nitrobenzene					<580		U	58.3								
8835-011	O,O,O-Triethylphosphorothioate					<580		U	58.3								
8835-011	o-Toluidine					<580		U	58.3								
8835-011	p-Dimethylaminoazobenzene					<580		U	58.3								
8835-011	p-Phenylenediamine					<580		U	58.3								
8835-011	Parathion					<580		U	58.3								
8835-011	Pentachlorobenzene					<580		U	58.3								
8835-011	Pentachloronitrobenzene					<580		U	58.3								
8835-011	Pentachlorophenol					<580		U	58.3								
8835-011	Phenacetin					<580		U	58.3								
8835-011	Phenol					<580		U	58.3								
8835-011	Phorate					<580		U	58.3								
8835-011	Pronamide					<580		U	58.3								
8835-011	Pyridine					<580		U	58.3								
8835-011	Safrole					<580		U	58.3								
8835-011	Sulfotepp					<580		U	58.3								
8835-011	Thionzin					<580		U	58.3								

COMPARATIVE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-001	1,3-Dichlorobenzene	<270	BQL	U	26.7	<1200	BQL	U	117	<200	BQL	U	19.8	<99	BQL	U	9.9
8835-001	1,3-Propane sultone	<13	BQL	U	1.3	<100	BQL	U	10.0	<100	BQL	U	10.0	<100	BQL	U	10.0
8835-001	2-Fluoroacetamide	<13	BQL	U	1.3	<100	BQL	U	10.0	<100	BQL	U	10.0	<100	BQL	U	10.0
8835-001	3,3'-Dimethoxybenzidine	<13	BQL	U	1.3	<100	BQL	U	10.0	<100	BQL	U	10.0	<100	BQL	U	10.0
8835-001	4,4'-methylene-bis(2-chloroaniline)	<13	BQL	U	1.3	<100	BQL	U	10.0	<100	BQL	U	10.0	<100	BQL	U	10.0
8835-001	4,6-Dinitro-2-methylphenol	<270	BQL	U	26.7	<1200	BQL	U	117	<200	BQL	U	19.8	<99	BQL	U	9.9
8835-001	4-Aminopyridine	<13	BQL	U	1.3	<100	BQL	U	10.0	<100	BQL	U	10.0	<100	BQL	U	10.0
8835-001	4-Bromophenyl phenyl ether	<270	BQL	U	26.7	<1200	BQL	U	117	<200	BQL	U	19.8	<99	BQL	U	9.9
8835-001	Acetone cyanohydrin	<13	BQL	U	1.3	<100	BQL	U	10.0	<100	BQL	U	10.0	<100	BQL	U	10.0
8835-001	Benzal chloride	<13	BQL	U	1.3	<100	BQL	U	10.0	<100	BQL	U	10.0	<100	BQL	U	10.0
8835-001	Benzyl chloride	<13	BQL	U	1.3	<100	BQL	U	10.0	<100	BQL	U	10.0	<100	BQL	U	10.0
8835-001	Bis(2-chloroethyl)ether	<270	BQL	U	26.7	<1200	BQL	U	117	<200	BQL	U	19.8	<99	BQL	U	9.9
8835-001	Bis(2-chloroethoxy)methane	<270	BQL	U	26.7	<1200	BQL	U	117	<200	BQL	U	19.8	<99	BQL	U	9.9
8835-001	Bis(2-ethylhexyl)phthalate	<270	BQL	U	26.7	<1200	BQL	U	117	<200	BQL	U	19.8	<99	BQL	U	9.9
8835-001	Endothall	<13	BQL	U	1.3	<100	BQL	U	10.0	<100	BQL	U	10.0	<100	BQL	U	10.0
8835-001	Ethyl carbamate	<13	BQL	U	1.3	<100	BQL	U	10.0	<100	BQL	U	10.0	<100	BQL	U	10.0
8835-001	Ethylene glycol monoethyl ether	<13	BQL	U	1.3	<100	BQL	U	10.0	<100	BQL	U	10.0	<100	BQL	U	10.0
8835-001	Ethylenethiourea (2-Imidazolidinethione)	<13	BQL	U	1.3	<12	BQL	U	1.2	<110	BQL	U	11.5	<100	BQL	U	10.0
8835-001	m-Dinitrobenzene	<270	BQL	U	26.7	<1200	BQL	U	117	<200	BQL	U	19.8	<99	BQL	U	9.9
8835-001	Methomyl	<6.7	BQL	U	1.3	<5.8	BQL	U	1.2	<57	BQL	U	11.5	<50	BQL	U	10.0
8835-001	MNNG (N-Metyl-N-nitroso-N'-nitroguanidine)	<13	BQL	U	1.3	<12	BQL	U	1.2	<110	BQL	U	11.5	<100	BQL	U	10.0
8835-001	N-Nitrosodiphenylamine	<270	BQL	U	26.7	<1200	BQL	U	117	<200	BQL	U	19.8	<99	BQL	U	9.9
8835-001	Nicotine	<13	BQL	U	1.3	<100	BQL	U	10.0	<100	BQL	U	10.0	<100	BQL	U	10.0
8835-001	Phenylthiourea	<6.7	BQL	U	1.3	<5.8	BQL	U	1.2	<57	BQL	U	11.5	<50	BQL	U	10.0
8835-001	p-Toluidine	<13	BQL	U	1.3	<100	BQL	U	10.0	<100	BQL	U	10.0	<100	BQL	U	10.0
8835-001	6-Propyl-2-thiouracil	<13	BQL	U	1.3	<100	BQL	U	10.0	<100	BQL	U	10.0	<100	BQL	U	10.0
8835-001	Strychnine	<13	BQL	U	1.3	<100	BQL	U	10.0	<100	BQL	U	10.0	<100	BQL	U	10.0
8835-001	Thioacetamide	<6.7	BQL	U	1.3	<5.8	BQL	U	1.2	<57	BQL	U	11.5	<50	BQL	U	10.0
8835-001	Thiofanox	<13	BQL	U	1.3	<100	BQL	U	10.0	<100	BQL	U	10.0	<100	BQL	U	10.0
8835-001	Thiourea	<6.7	BQL	U	1.3	<5.8	BQL	U	1.2	<57	BQL	U	11.5	<50	BQL	U	10.0
8835-001	Toluene-2,4-diamine	<6.7	BQL	U	1.3	<5.8	BQL	U	1.2	<57	BQL	U	11.5	<50	BQL	U	10.0
8835-001	Toluene-2,6-diamine	<6.7	BQL	U	1.3	<5.8	BQL	U	1.2	<57	BQL	U	11.5	<50	BQL	U	10.0
8835-001	gamma-BHC (Lindane)	<1.3	BQL	U	134	<1.2	BQL	U	117	<1.1	BQL	U	115	<1.0	BQL	U	102
8835-001	Heptachlor	<1.3	BQL	U	134	<1.2	BQL	U	117	<1.1	BQL	U	115	<1.0	BQL	U	102
8835-001	Heptachlor epoxide	<2.7	BQL	U	134	<2.3	BQL	U	117	<2.3	BQL	U	115	<2.0	BQL	U	102

COMPARATIVE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	*Fuel = Gasoline*				*Fuel = No.2*				*Fuel = No.4*				*Fuel = No.6*			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-001	Endosulfan I	<1.3	BQL	U	134	<1.2	BQL	U	117	<1.1	BQL	U	115	<1.0	BQL	U	102
8835-001	Endrin	<1.3	BQL	U	134	<1.2	BQL	U	117	<1.1	BQL	U	115	<1.0	BQL	U	102
8835-001	Endosulfan II	<1.3	BQL	U	134	<1.2	BQL	U	117	<1.1	BQL	U	115	<1.0	BQL	U	102
8835-001	Chlordane	<13	BQL	U	134	<12	BQL	U	117	<11	BQL	U	115	<10	BQL	U	102
8835-001	Endrin aldehyde	<1.3	BQL	U	134	<1.2	BQL	U	117	<1.1	BQL	U	115	<1.0	BQL	U	102
8835-001	Endrin ketone	<1.3	BQL	U	134	<1.2	BQL	U	117	<1.1	BQL	U	115	<1.0	BQL	U	102
8835-001	2,4-D	<6.7	BQL	U	134	<5.8	BQL	U	117	<5.7	BQL	U	115	<5.1	BQL	U	102
8835-001	Silvex	<6.7	BQL	U	134	<5.8	BQL	U	117	<5.7	BQL	U	115	<5.1	BQL	U	102
8835-001	2,3,7,8-Tetrachlorodibenzo-p-dioxin	<3.3	BQL	U	1.3	<29	BQL	U	11.7	<29	BQL	U	11.5	<25	BQL	U	10.2
8835-002	1,3-Dichlorobenzene	<270	BQL	U	26.6	<1200	BQL	U	117					<200	BQL	U	19.6
8835-002	1,3-Propane sultone	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-002	2-Fluoroacetamide	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-002	3,3'-Dimethoxybenzidine	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-002	4,4'-methylene-bis(2-chloroaniline)	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-002	4,6-Dinitro-2-methylphenol	<270	BQL	U	26.6	<1200	BQL	U	117					<200	BQL	U	19.6
8835-002	4-Aminopyridine	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-002	4-Bromophenyl phenyl ether	<270	BQL	U	26.6	<1200	BQL	U	117					<200	BQL	U	19.6
8835-002	Acetone cyanohydrin	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-002	Benzal chloride	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-002	Benzyl chloride	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-002	Bis(2-chloroethyl)ether	<270	BQL	U	26.6	<1200	BQL	U	117					<200	BQL	U	19.6
8835-002	Bis(2-chloroethoxy)methane	<270	BQL	U	26.6	<1200	BQL	U	117					<200	BQL	U	19.6
8835-002	Bis(2-ethylhexyl)phthalate	<270	BQL	U	26.6	<1200	BQL	U	117					<200	BQL	U	19.6
8835-002	Endothall	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-002	Ethyl carbamate	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-002	Ethylene glycol monoethyl ether	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-002	Ethylenethiourea (2-Imidazolidinethione)	<13	BQL	U	1.3	<12	BQL	U	1.2					<100	BQL	U	10.0
8835-002	m-Dinitrobenzene	<270	BQL	U	26.6	<1200	BQL	U	117					<200	BQL	U	19.6
8835-002	Methomyl	<6.6	BQL	U	1.3	<5.8	BQL	U	1.2					<50	BQL	U	10.0
8835-002	MNNG (N-Metyl-N-nitroso-N'-nitroguanidine)	<13	BQL	U	1.3	<12	BQL	U	1.2					<100	BQL	U	10.0
8835-002	N-Nitrosodiphenylamine	<270	BQL	U	26.6	<1200	BQL	U	117					<200	BQL	U	19.6
8835-002	Nicotine	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-002	Phenylthiourea	<6.6	BQL	U	1.3	<5.8	BQL	U	1.2					<50	BQL	U	10.0
8835-002	p-Toluidine	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0

COMPARATIVE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-002	6-Propyl-2-thiouracil	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-002	Strychnine	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-002	Thioacetamide	<6.6	BQL	U	1.3	<5.8	BQL	U	1.2					<50	BQL	U	10.0
8835-002	Thiofanox	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-002	Thiourea	<6.6	BQL	U	1.3	<5.8	BQL	U	1.2					<50	BQL	U	10.0
8835-002	Toluene-2,4-diamine	<6.6	BQL	U	1.3	<5.8	BQL	U	1.2					<50	BQL	U	10.0
8835-002	Toluene-2,6-diamine	<6.6	BQL	U	1.3	<5.8	BQL	U	1.2					<50	BQL	U	10.0
8835-002	gamma-BHC (Lindane)	<1.3	BQL	U	133	<1.2	BQL	U	117					<1.0	BQL	U	101
8835-002	Heptachlor	<1.3	BQL	U	133	<1.2	BQL	U	117					<1.0	BQL	U	101
8835-002	Heptachlor epoxide	<2.7	BQL	U	133	<2.3	BQL	U	117					<2.0	BQL	U	101
8835-002	Endosulfan I	<1.3	BQL	U	133	<1.2	BQL	U	117					<1.0	BQL	U	101
8835-002	Endrin	<1.3	BQL	U	133	<1.2	BQL	U	117					<1.0	BQL	U	101
8835-002	Endosulfan II	<1.3	BQL	U	133	<1.2	BQL	U	117					<1.0	BQL	U	101
8835-002	Chlordane	<13	BQL	U	133	<12	BQL	U	117					<10	BQL	U	101
8835-002	Endrin aldehyde	<1.3	BQL	U	133	<1.2	BQL	U	117					<1.0	BQL	U	101
8835-002	Endrin ketone	<1.3	BQL	U	133	<1.2	BQL	U	117					<1.0	BQL	U	101
8835-002	2,4-D	<6.6	BQL	U	133	<5.8	BQL	U	117					<5.1	BQL	U	101
8835-002	Silvex	<6.6	BQL	U	133	<5.8	BQL	U	117					<5.1	BQL	U	101
8835-002	2,3,7,8-Tetrachlorodibenzo-p-dioxin	<3.3	BQL	U	1.3	<29	BQL	U	11.7					<25	BQL	U	10.1
8835-003	1,3-Dichlorobenzene	<670	BQL	U	66.8	<590	BQL	U	59.4					<190	BQL	U	19.2
8835-003	1,3-Propane sultone	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-003	2-Fluoroacetamide	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-003	3,3'-Dimethoxybenzidine	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-003	4,4'-methylene-bis(2-chloroaniline)	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-003	4,6-Dinitro-2-methylphenol	<670	BQL	U	66.8	<590	BQL	U	59.4					<190	BQL	U	19.2
8835-003	4-Aminopyridine	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-003	4-Bromophenyl phenyl ether	<670	BQL	U	66.8	<590	BQL	U	59.4					<190	BQL	U	19.2
8835-003	Acetone cyanohydrin	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-003	Benzal chloride	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-003	Benzyl chloride	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-003	Bis(2-chloroethyl)ether	<670	BQL	U	66.8	<590	BQL	U	59.4					<190	BQL	U	19.2
8835-003	Bis(2-chloroethoxy)methane	<670	BQL	U	66.8	<590	BQL	U	59.4					<190	BQL	U	19.2
8835-003	Bis(2-ethylhexyl)phthalate	<670	BQL	U	66.8	<590	BQL	U	59.4					<190	BQL	U	19.2
8835-003	Endothall	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-003	Ethyl carbamate	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-003	Ethylene glycol monoethyl ether	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0

COMPARATIVE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	*Fuel = Gasoline*				*Fuel = No.2*				*Fuel = No.4*				*Fuel = No.6*			
		Q.L.	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**
8835-003	Ethylenethiourea (2-Imidazolidinethione)	<13	BQL	U	1.3	<12	BQL	U	1.2					<100	BQL	U	10.0
8835-003	m-Dinitrobenzene	<670	BQL	U	66.8	<590	BQL	U	59.4					<190	BQL	U	19.2
8835-003	Methomyl	<6.7	BQL	U	1.3	<5.9	BQL	U	1.2					<50	BQL	U	10.0
8835-003	MNNG (N-Metyl-N-nitroso-N'-nitroguanidine)	<13	BQL	U	1.3	<12	BQL	U	1.2					<100	BQL	U	10.0
8835-003	N-Nitrosodiphenylamine	<670	BQL	U	66.8	<590	BQL	U	59.4					<190	BQL	U	19.2
8835-003	Nicotine	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-003	Phenylthiourea	<6.7	BQL	U	1.3	<5.9	BQL	U	1.2					<50	BQL	U	10.0
8835-003	p-Toluidine	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-003	6-Propyl-2-thiouracil	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-003	Strychnine	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-003	Thioacetamide	<6.7	BQL	U	1.3	<5.9	BQL	U	1.2					<50	BQL	U	10.0
8835-003	Thiofanox	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-003	Thiourea	<6.7	BQL	U	1.3	<5.9	BQL	U	1.2					<50	BQL	U	10.0
8835-003	Toluene-2,4-diamine	<6.7	BQL	U	1.3	<5.9	BQL	U	1.2					<50	BQL	U	10.0
8835-003	Toluene-2,6-diamine	<6.7	BQL	U	1.3	<5.9	BQL	U	1.2					<50	BQL	U	10.0
8835-003	gamma-BHC (Lindane)	<1.3	BQL	U	134	<1.2	BQL	U	119					<1.0	BQL	U	101
8835-003	Heptachlor	<1.3	BQL	U	134	<1.2	BQL	U	119					<1.0	BQL	U	101
8835-003	Heptachlor epoxide	<2.7	BQL	U	134	<2.4	BQL	U	119					<2.0	BQL	U	101
8835-003	Endosulfan I	<1.3	BQL	U	134	<1.2	BQL	U	119					<1.0	BQL	U	101
8835-003	Endrin	<1.3	BQL	U	134	<1.2	BQL	U	119					<1.0	BQL	U	101
8835-003	Endosulfan II	<1.3	BQL	U	134	<1.2	BQL	U	119					<1.0	BQL	U	101
8835-003	Chlordane	<13	BQL	U	134	<12	BQL	U	119					<10	BQL	U	101
8835-003	Endrin aldehyde	<1.3	BQL	U	134	<1.2	BQL	U	119					<1.0	BQL	U	101
8835-003	Endrin ketone	<1.3	BQL	U	134	<1.2	BQL	U	119					<1.0	BQL	U	101
8835-003	2,4-D	<6.7	BQL	U	134	<5.9	BQL	U	119					<5.0	BQL	U	101
8835-003	Silvex	<6.7	BQL	U	134	<5.9	BQL	U	119					<5.0	BQL	U	101
8835-003	2,3,7,8-Tetrachlorodibenzo-p-dioxin	<3.3	BQL	U	1.3	<30	BQL	U	11.9					<25	BQL	U	10.1
8835-004	1,3-Dichlorobenzene	<670	BQL	U	66.7	<600	BQL	U	59.6					<500	BQL	U	50.0
8835-004	1,3-Propane sultone	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-004	2-Fluoroacetamide	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-004	3,3'-Dimethoxybenzidine	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-004	4,4'-methylene-bis(2-chloroaniline)	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-004	4,6-Dinitro-2-methylphenol	<670	BQL	U	66.7	<600	BQL	U	59.6					<500	BQL	U	50.0
8835-004	4-Aminopyridine	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0

COMPARATIVE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-004	4-Bromophenyl phenyl ether	<670	BQL	U	66.7	<600	BQL	U	59.6					<500	BQL	U	50.0
8835-004	Acetone cyanohydrin	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-004	Benzal chloride	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-004	Benzyl chloride	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-004	Bis(2-chloroethyl)ether	<670	BQL	U	66.7	<600	BQL	U	59.6					<500	BQL	U	50.0
8835-004	Bis(2-chloroethoxy)methane	<670	BQL	U	66.7	<600	BQL	U	59.6					<500	BQL	U	50.0
8835-004	Bis(2-ethylhexyl)phthalate	<670	BQL	U	66.7	<600	BQL	U	59.6					<500	BQL	U	50.0
8835-004	Endothall	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-004	Ethyl carbamate	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-004	Ethylene glycol monoethyl ether	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-004	Ethylenethiourea (2-Imidazolidinethione)	<13	BQL	U	1.3	<12	BQL	U	1.2					<100	BQL	U	10.0
8835-004	m-Dinitrobenzene	<670	BQL	U	66.7	<600	BQL	U	59.6					<500	BQL	U	50.0
8835-004	Methomyl	<6.7	BQL	U	1.3	<6.0	BQL	U	1.2					<50	BQL	U	10.0
8835-004	MNNG (N-Metyl-N-nitroso-N'-nitroguanidine)	<13	BQL	U	1.3	<12	BQL	U	1.2					<100	BQL	U	10.0
8835-004	N-Nitrosodiphenylamine	<670	BQL	U	66.7	<600	BQL	U	59.6					<500	BQL	U	50.0
8835-004	Nicotine	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-004	Phenylthiourea	<6.7	BQL	U	1.3	<6.0	BQL	U	1.2					<50	BQL	U	10.0
8835-004	p-Toluidine	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-004	6-Propyl-2-thiouracil	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-004	Strychnine	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-004	Thioacetamide	<6.7	BQL	U	1.3	<6.0	BQL	U	1.2					<50	BQL	U	10.0
8835-004	Thiofanox	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-004	Thiourea	<6.7	BQL	U	1.3	<6.0	BQL	U	1.2					<50	BQL	U	10.0
8835-004	Toluene-2,4-diamine	<6.7	BQL	U	1.3	<6.0	BQL	U	1.2					<50	BQL	U	10.0
8835-004	Toluene-2,6-diamine	<6.7	BQL	U	1.3	<6.0	BQL	U	1.2					<50	BQL	U	10.0
8835-004	gamma-BHC (Lindane)	<1.3	BQL	U	133	<1.2	BQL	U	119					<1.0	BQL	U	101
8835-004	Heptachlor	<1.3	BQL	U	133	<1.2	BQL	U	119					<1.0	BQL	U	101
8835-004	Heptachlor epoxide	<2.7	BQL	U	133	<2.4	BQL	U	119					<2.0	BQL	U	101
8835-004	Endosulfan I	<1.3	BQL	U	133	<1.2	BQL	U	119					<1.0	BQL	U	101
8835-004	Endrin	<1.3	BQL	U	133	<1.2	BQL	U	119					<1.0	BQL	U	101
8835-004	Endosulfan II	<1.3	BQL	U	133	<1.2	BQL	U	119					<1.0	BQL	U	101
8835-004	Chlordane	<13	BQL	U	133	<12	BQL	U	119					<10	BQL	U	101
8835-004	Endrin aldehyde	<1.3	BQL	U	133	<1.2	BQL	U	119					<1.0	BQL	U	101
8835-004	Endrin ketone	<1.3	BQL	U	133	<1.2	BQL	U	119					<1.0	BQL	U	101
8835-004	2,4-D	<6.7	BQL	U	133	<6.0	BQL	U	119					<5.0	BQL	U	101
8835-004	Silvex	<6.7	BQL	U	133	<6.0	BQL	U	119					<5.0	BQL	U	101

COMPARATIVE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-004	2,3,7,8-Tetrachlorodibenzo-p-dioxin	<3.3	BQL	U	1.3	<30	BQL	U	11.9					<25	BQL	U	10.1
8835-005	1,3-Dichlorobenzene	<130	BQL	U	13.4	<590	BQL	U	59.5					<200	BQL	U	19.8
8835-005	1,3-Propane sultone	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-005	2-Fluoroacetamide	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-005	3,3'-Dimethoxybenzidine	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-005	4,4'-methylene-bis(2-chloroaniline)	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-005	4,6-Dinitro-2-methylphenol	<130	BQL	U	13.4	<590	BQL	U	59.5					<200	BQL	U	19.8
8835-005	4-Aminopyridine	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-005	4-Bromophenyl phenyl ether	<130	BQL	U	13.4	<590	BQL	U	59.5					<200	BQL	U	19.8
8835-005	Acetone cyanohydrin	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-005	Benzal chloride	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-005	Benzyl chloride	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-005	Bis(2-chloroethyl)ether	<130	BQL	U	13.4	<590	BQL	U	59.5					<200	BQL	U	19.8
8835-005	Bis(2-chloroethoxy)methane	<130	BQL	U	13.4	<590	BQL	U	59.5					<200	BQL	U	19.8
8835-005	Bis(2-ethylhexyl)phthalate	<130	BQL	U	13.4	<590	BQL	U	59.5					<200	BQL	U	19.8
8835-005	Endothall	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-005	Ethyl carbamate	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-005	Ethylene glycol monoethyl ether	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-005	Ethylenethiourea (2-Imidazolidinethione)	<13	BQL	U	1.3	<12	BQL	U	1.2					<100	BQL	U	10.0
8835-005	m-Dinitrobenzene	<130	BQL	U	13.4	<590	BQL	U	59.5					<200	BQL	U	19.8
8835-005	Methomyl	<6.7	BQL	U	1.3	<5.9	BQL	U	1.2					<50	BQL	U	10.0
8835-005	MNNG (N-Metyl-N-nitroso-N'-nitroguanidine)	<13	BQL	U	1.3	<12	BQL	U	1.2					<100	BQL	U	10.0
8835-005	N-Nitrosodiphenylamine	<130	BQL	U	13.4	<590	BQL	U	59.5					<200	BQL	U	19.8
8835-005	Nicotine	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-005	Phenylthiourea	<6.7	BQL	U	1.3	<5.9	BQL	U	1.2					<50	BQL	U	10.0
8835-005	p-Toluidine	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-005	6-Propyl-2-thiouracil	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-005	Strychnine	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-005	Thioacetamide	<6.7	BQL	U	1.3	<5.9	BQL	U	1.2					<50	BQL	U	10.0
8835-005	Thiofanox	<13	BQL	U	1.3	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-005	Thiourea	<6.7	BQL	U	1.3	<5.9	BQL	U	1.2					<50	BQL	U	10.0
8835-005	Toluene-2,4-diamine	<6.7	BQL	U	1.3	<5.9	BQL	U	1.2					<50	BQL	U	10.0
8835-005	Toluene-2,6-diamine	<6.7	BQL	U	1.3	<5.9	BQL	U	1.2					<50	BQL	U	10.0
8835-005	gamma-BHC (Lindane)	<1.3	BQL	U	134	<1.2	BQL	U	119					<1.0	BQL	U	101

COMPARATIVE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	*Fuel = Gasoline*				*Fuel = No.2*				*Fuel = No.4*				*Fuel = No.6*			
		Q.L.	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**
8835-005	Heptachlor	<1.3	BQL	U	134	<1.2	BQL	U	119					<1.0	BQL	U	101
8835-005	Heptachlor epoxide	<2.7	BQL	U	134	<2.4	BQL	U	119					<2.0	BQL	U	101
8835-005	Endosulfan I	<1.3	BQL	U	134	<1.2	BQL	U	119					<1.0	BQL	U	101
8835-005	Endrin	<1.3	BQL	U	134	<1.2	BQL	U	119					<1.0	BQL	U	101
8835-005	Endosulfan II	<1.3	BQL	U	134	<1.2	BQL	U	119					<1.0	BQL	U	101
8835-005	Chlordane	<13	BQL	U	134	<12	BQL	U	119					<10	BQL	U	101
8835-005	Endrin aldehyde	<1.3	BQL	U	134	<1.2	BQL	U	119					<1.0	BQL	U	101
8835-005	Endrin ketone	<1.3	BQL	U	134	<1.2	BQL	U	119					<1.0	BQL	U	101
8835-005	2,4-D	<6.7	BQL	U	134	<5.9	BQL	U	119					<5.0	BQL	U	101
8835-005	Silvex	<6.7	BQL	U	134	<5.9	BQL	U	119					<5.0	BQL	U	101
8835-005	2,3,7,8-Tetrachlorodibenzo-p-dioxin	<3.4	BQL	U	1.3	<30	BQL	U	11.9					<25	BQL	U	10.1
8835-006	1,3-Dichlorobenzene	<140	BQL	U	14.1	<290	BQL	U	29.3					<980	BQL	U	98.0
8835-006	1,3-Propane sultone	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-006	2-Fluoroacetamide	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-006	3,3'-Dimethoxybenzidine	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-006	4,4'-methylene-bis(2-chloroaniline)	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-006	4,6-Dinitro-2-methylphenol	<140	BQL	U	14.1	<290	BQL	U	29.3					<980	BQL	U	98.0
8835-006	4-Aminopyridine	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-006	4-Bromophenyl phenyl ether	<140	BQL	U	14.1	<290	BQL	U	29.3					<980	BQL	U	98.0
8835-006	Acetone cyanohydrin	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-006	Benzal chloride	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-006	Benzyl chloride	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-006	Bis(2-chloroethyl)ether	<140	BQL	U	14.1	<290	BQL	U	29.3					<980	BQL	U	98.0
8835-006	Bis(2-chloroethoxy)methane	<140	BQL	U	14.1	<290	BQL	U	29.3					<980	BQL	U	98.0
8835-006	Bis(2-ethylhexyl)phthalate	<140	BQL	U	14.1	<290	BQL	U	29.3					<980	BQL	U	98.0
8835-006	Endothall	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-006	Ethyl carbamate	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-006	Ethylene glycol monoethyl ether	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-006	Ethylenethiourea (2-Imidazolidinethione)	<14	BQL	U	1.4	<12	BQL	U	1.2					<100	BQL	U	10.0
8835-006	m-Dinitrobenzene	<140	BQL	U	14.1	<290	BQL	U	29.3					<980	BQL	U	98.0
8835-006	Methomyl	<7	BQL	U	1.4	<5.8	BQL	U	1.2					<50	BQL	U	10.0
8835-006	MNNG (N-Metyl-N-nitroso-N'-nitroguanidine)	<14	BQL	U	1.4	<12	BQL	U	1.2					<100	BQL	U	10.0
8835-006	N-Nitrosodiphenylamine	<140	BQL	U	14.1	<290	BQL	U	29.3					<980	BQL	U	98.0
8835-006	Nicotine	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0

COMPARATIVE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	*Fuel = Gasoline*				*Fuel = No.2*				*Fuel = No.4*				*Fuel = No.6*			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-006	Phenylthiourea	<7	BQL	U	1.4	<5.8	BQL	U	1.2					<50	BQL	U	10.0
8835-006	p-Toluidine	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-006	6-Propyl-2-thiouracil	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-006	Strychnine	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-006	Thioacetamide	<7	BQL	U	1.4	<5.8	BQL	U	1.2					<50	BQL	U	10.0
8835-006	Thiofanox	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-006	Thiourea	<7	BQL	U	1.4	<5.8	BQL	U	1.2					<50	BQL	U	10.0
8835-006	Toluene-2,4-diamine	<7	BQL	U	1.4	<5.8	BQL	U	1.2					<50	BQL	U	10.0
8835-006	Toluene-2,6-diamine	<7	BQL	U	1.4	<5.8	BQL	U	1.2					<50	BQL	U	10.0
8835-006	gamma-BHC (Lindane)	<1.4	BQL	U	141	<1.2	BQL	U	117					<1.0	BQL	U	102
8835-006	Heptachlor	<1.4	BQL	U	141	<1.2	BQL	U	117					<1.0	BQL	U	102
8835-006	Heptachlor epoxide	<2.8	BQL	U	141	<2.3	BQL	U	117					<2.0	BQL	U	102
8835-006	Endosulfan I	<1.4	BQL	U	141	<1.2	BQL	U	117					<1.0	BQL	U	102
8835-006	Endrin	<1.4	BQL	U	141	<1.2	BQL	U	117					<1.0	BQL	U	102
8835-006	Endosulfan II	<1.4	BQL	U	141	<1.2	BQL	U	117					<1.0	BQL	U	102
8835-006	Chlordane	<14	BQL	U	141	<12	BQL	U	117					<10	BQL	U	102
8835-006	Endrin aldehyde	<1.4	BQL	U	141	<1.2	BQL	U	117					<1.0	BQL	U	102
8835-006	Endrin ketone	<1.4	BQL	U	141	<1.2	BQL	U	117					<1.0	BQL	U	102
8835-006	2,4-D	<7	BQL	U	141	<5.8	BQL	U	117					<5.1	BQL	U	102
8835-006	Silvex	<7	BQL	U	141	<5.8	BQL	U	117					<5.1	BQL	U	102
8835-006	2,3,7,8-Tetrachlorodibenzo-p-dioxin	<3.5	BQL	U	1.4	<29	BQL	U	11.7					<26	BQL	U	10.2
8835-007	1,3-Dichlorobenzene	<270	BQL	U	27.4	<2400	BQL	U	235					<200	BQL	U	19.6
8835-007	1,3-Propane sultone	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-007	2-Fluoroacetamide	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-007	3,3'-Dimethoxybenzidine	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-007	4,4'-methylene-bis(2-chloroaniline)	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-007	4,6-Dinitro-2-methylphenol	<270	BQL	U	27.4	<2400	BQL	U	235					<200	BQL	U	19.6
8835-007	4-Aminopyridine	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-007	4-Bromophenyl phenyl ether	<270	BQL	U	27.4	<2400	BQL	U	235					<200	BQL	U	19.6
8835-007	Acetone cyanohydrin	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-007	Benzal chloride	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-007	Benzyl chloride	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-007	Bis(2-chloroethyl)ether	<270	BQL	U	27.4	<2400	BQL	U	235					<200	BQL	U	19.6
8835-007	Bis(2-chloroethoxy)methane	<270	BQL	U	27.4	<2400	BQL	U	235					<200	BQL	U	19.6
8835-007	Bis(2-ethylhexyl)phthalate	<270	BQL	U	27.4	<2400	BQL	U	235					<200	BQL	U	19.6
8835-007	Endothall	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0

COMPARATIVE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	*Fuel = Gasoline*				*Fuel = No.2*				*Fuel = No.4*				*Fuel = No.6*			
		Q.L.	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**
8835-007	Ethyl carbamate	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-007	Ethylene glycol monoethyl ether	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-007	Ethylenethiourea (2-Imidazolidinethione)	<14	BQL	U	1.4	<12	BQL	U	1.2					<100	BQL	U	10.0
8835-007	m-Dinitrobenzene	<270	BQL	U	27.4	<2400	BQL	U	235					<200	BQL	U	19.6
8835-007	Methomyl	<6.8	BQL	U	1.4	<5.9	BQL	U	1.2					<50	BQL	U	10.0
8835-007	MNNG (N-Metyl-N-nitroso-N'-nitroguanidine)	<14	BQL	U	1.4	<12	BQL	U	1.2					<100	BQL	U	10.0
8835-007	N-Nitrosodiphenylamine	<270	BQL	U	27.4	<2400	BQL	U	235					<200	BQL	U	19.6
8835-007	Nicotine	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-007	Phenylthiourea	<6.8	BQL	U	1.4	<5.9	BQL	U	1.2					<50	BQL	U	10.0
8835-007	p-Toluidine	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-007	6-Propyl-2-thiouracil	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-007	Strychnine	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-007	Thioacetamide	<6.8	BQL	U	1.4	<5.9	BQL	U	1.2					<50	BQL	U	10.0
8835-007	Thiofanox	<14	BQL	U	1.4	<100	BQL	U	10.0					<100	BQL	U	10.0
8835-007	Thiourea	<6.8	BQL	U	1.4	<5.9	BQL	U	1.2					<50	BQL	U	10.0
8835-007	Toluene-2,4-diamine	<6.8	BQL	U	1.4	<5.9	BQL	U	1.2					<50	BQL	U	10.0
8835-007	Toluene-2,6-diamine	<6.8	BQL	U	1.4	<5.9	BQL	U	1.2					<50	BQL	U	10.0
8835-007	gamma-BHC (Lindane)	<1.4	BQL	U	137	<1.2	BQL	U	118					<1.0	BQL	U	101
8835-007	Heptachlor	<1.4	BQL	U	137	<1.2	BQL	U	118					<1.0	BQL	U	101
8835-007	Heptachlor epoxide	<2.7	BQL	U	137	<2.4	BQL	U	118					<2.0	BQL	U	101
8835-007	Endosulfan I	<1.4	BQL	U	137	<1.2	BQL	U	118					<1.0	BQL	U	101
8835-007	Endrin	<1.4	BQL	U	137	<1.2	BQL	U	118					<1.0	BQL	U	101
8835-007	Endosulfan II	<1.4	BQL	U	137	<1.2	BQL	U	118					<1.0	BQL	U	101
8835-007	Chlordane	<14	BQL	U	137	<12	BQL	U	118					<10	BQL	U	101
8835-007	Endrin aldehyde	<1.4	BQL	U	137	<1.2	BQL	U	118					<1.0	BQL	U	101
8835-007	Endrin ketone	<1.4	BQL	U	137	<1.2	BQL	U	118					<1.0	BQL	U	101
8835-007	2,4-D	<6.8	BQL	U	137	<5.9	BQL	U	118					<5.0	BQL	U	101
8835-007	Silvex	<6.8	BQL	U	137	<5.9	BQL	U	118					<5.0	BQL	U	101
8835-007	2,3,7,8-Tetrachlorodibenzo-p-dioxin	<3.4	BQL	U	1.4	<29	BQL	U	11.8					<25	BQL	U	10.1
8835-008	1,3-Dichlorobenzene	<280	BQL	U	27.7	<600	BQL	U	59.7								
8835-008	1,3-Propane sultone	<14	BQL	U	1.4	<100	BQL	U	10.0								
8835-008	2-Fluoroacetamide	<14	BQL	U	1.4	<100	BQL	U	10.0								
8835-008	3,3'-Dimethoxybenzidine	<14	BQL	U	1.4	<100	BQL	U	10.0								
8835-008	4,4'-methylene-bis(2-chloroaniline)	<14	BQL	U	1.4	<100	BQL	U	10.0								

COMPARATIVE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	*Fuel = Gasoline*				*Fuel = No.2*				*Fuel = No.4*				*Fuel = No.6*			
		Q.L.	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**
8835-008	4,6-Dinitro-2-methylphenol	<280	BQL	U	27.7	<600	BQL	U	59.7								
8835-008	4-Aminopyridine	<14	BQL	U	1.4	<100	BQL	U	10.0								
8835-008	4-Bromophenyl phenyl ether	<280	BQL	U	27.7	<600	BQL	U	59.7								
8835-008	Acetone cyanohydrin	<14	BQL	U	1.4	<100	BQL	U	10.0								
8835-008	Benzal chloride	<14	BQL	U	1.4	<100	BQL	U	10.0								
8835-008	Benzyl chloride	<14	BQL	U	1.4	<100	BQL	U	10.0								
8835-008	Bis(2-chloroethyl)ether	<280	BQL	U	27.7	<600	BQL	U	59.7								
8835-008	Bis(2-chloroethoxy)methane	<280	BQL	U	27.7	<600	BQL	U	59.7								
8835-008	Bis(2-ethylhexyl)phthalate	<280	BQL	U	27.7	<600	BQL	U	59.7								
8835-008	Endothall	<14	BQL	U	1.4	<100	BQL	U	10.0								
8835-008	Ethyl carbamate	<14	BQL	U	1.4	<100	BQL	U	10.0								
8835-008	Ethylene glycol monoethyl ether	<14	BQL	U	1.4	<100	BQL	U	10.0								
8835-008	Ethylenethiourea (2-Imidazolidinethione)	<14	BQL	U	1.4	<12	BQL	U	1.2								
8835-008	m-Dinitrobenzene	<280	BQL	U	27.7	<600	BQL	U	59.7								
8835-008	Methomyl	<6.9	BQL	U	1.4	<6.0	BQL	U	1.2								
8835-008	MNNG (N-Metyl-N-nitroso-N'-nitroguanidine)	<14	BQL	U	1.4	<12	BQL	U	1.2								
8835-008	N-Nitrosodiphenylamine	<280	BQL	U	27.7	<600	BQL	U	59.7								
8835-008	Nicotine	<14	BQL	U	1.4	<100	BQL	U	10.0								
8835-008	Phenylthiourea	<6.9	BQL	U	1.4	<6.0	BQL	U	1.2								
8835-008	p-Toluidine	<14	BQL	U	1.4	<100	BQL	U	10.0								
8835-008	6-Propyl-2-thiouracil	<14	BQL	U	1.4	<100	BQL	U	10.0								
8835-008	Strychnine	<14	BQL	U	1.4	<100	BQL	U	10.0								
8835-008	Thioacetamide	<6.9	BQL	U	1.4	<6.0	BQL	U	1.2								
8835-008	Thiofanox	<14	BQL	U	1.4	<100	BQL	U	10.0								
8835-008	Thiourea	<6.9	BQL	U	1.4	<6.0	BQL	U	1.2								
8835-008	Toluene-2,4-diamine	<6.9	BQL	U	1.4	<6.0	BQL	U	1.2								
8835-008	Toluene-2,6-diamine	<6.9	BQL	U	1.4	<6.0	BQL	U	1.2								
8835-008	gamma-BHC (Lindane)	<1.4	BQL	U	139	<1.2	BQL	U	120								
8835-008	Heptachlor	<1.4	BQL	U	139	<1.2	BQL	U	120								
8835-008	Heptachlor epoxide	<2.8	BQL	U	139	<2.4	BQL	U	120								
8835-008	Endosulfan I	<1.4	BQL	U	139	<1.2	BQL	U	120								
8835-008	Endrin	<1.4	BQL	U	139	<1.2	BQL	U	120								
8835-008	Endosulfan II	<1.4	BQL	U	139	<1.2	BQL	U	120								
8835-008	Chlordane	<14	BQL	U	139	<12	BQL	U	120								
8835-008	Endrin aldehyde	<1.4	BQL	U	139	<1.2	BQL	U	120								
8835-008	Endrin ketone	<1.4	BQL	U	139	<1.2	BQL	U	120								

COMPARATIVE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline Q.L.	Fuel = Gasoline Quant-itation	Fuel = Gasoline Code	Fuel = Gasoline D.F.	Fuel = No.2 Q.L.	Fuel = No.2 Quant-itation	Fuel = No.2 Code	Fuel = No.2 D.F.	Fuel = No.4 Q.L.	Fuel = No.4 Quant-itation	Fuel = No.4 Code	Fuel = No.4 D.F.	Fuel = No.6 Q.L.	Fuel = No.6 Quant-itation	Fuel = No.6 Code	Fuel = No.6 D.F.
8835-008	2,4-D	<6.9	BQL	U	139	<6.0	BQL	U	120								
8835-008	Silvex	<6.9	BQL	U	139	<6.0	BQL	U	120								
8835-008	2,3,7,8-Tetrachlorodibenzo-p-dioxin	<3.5	BQL	U	1.4	<30	BQL	U	11.9								
8835-009	1,3-Dichlorobenzene					<600	BQL	U	60.1								
8835-009	1,3-Propane sultone					<100	BQL	U	10.0								
8835-009	2-Fluoroacetamide					<100	BQL	U	10.0								
8835-009	3,3'-Dimethoxybenzidine					<100	BQL	U	10.0								
8835-009	4,4'-methylene-bis(2-chloroaniline)					<100	BQL	U	10.0								
8835-009	4,6-Dinitro-2-methylphenol					<600	BQL	U	60.1								
8835-009	4-Aminopyridine					<100	BQL	U	10.0								
8835-009	4-Bromophenyl phenyl ether					<600	BQL	U	60.1								
8835-009	Acetone cyanohydrin					<100	BQL	U	10.0								
8835-009	Benzal chloride					<100	BQL	U	10.0								
8835-009	Benzyl chloride					<100	BQL	U	10.0								
8835-009	Bis(2-chloroethyl)ether					<600	BQL	U	60.1								
8835-009	Bis(2-chloroethoxy)methane					<600	BQL	U	60.1								
8835-009	Bis(2-ethylhexyl)phthalate					<600	BQL	U	60.1								
8835-009	Endothall					<100	BQL	U	10.0								
8835-009	Ethyl carbamate					<100	BQL	U	10.0								
8835-009	Ethylene glycol monoethyl ether					<100	BQL	U	10.0								
8835-009	Ethylenethiourea (2-Imidazolidinethione)					<12	BQL	U	1.2								
8835-009	m-Dinitrobenzene					<600	BQL	U	60.1								
8835-009	Methomyl					<6.0	BQL	U	1.2								
8835-009	MNNG (N-Metyl-N-nitroso-N'-nitroguanidine)					<12	BQL	U	1.2								
8835-009	N-Nitrosodiphenylamine					<600	BQL	U	60.1								
8835-009	Nicotine					<100	BQL	U	10.0								
8835-009	Phenylthiourea					<6.0	BQL	U	1.2								
8835-009	p-Toluidine					<100	BQL	U	10.0								
8835-009	6-Propyl-2-thiouracil					<100	BQL	U	10.0								
8835-009	Strychnine					<100	BQL	U	10.0								
8835-009	Thioacetamide					<6.0	BQL	U	1.2								
8835-009	Thiofanox					<100	BQL	U	10.0								
8835-009	Thiourea					<6.0	BQL	U	1.2								
8835-009	Toluene-2,4-diamine					<6.0	BQL	U	1.2								

COMPARATIVE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	***Fuel = Gasoline***				***Fuel = No.2***				***Fuel = No.4***				***Fuel = No.6***			
		Q.L.	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**
8835-009	Toluene-2,6-diamine					<6.0	BQL	U	1.2								
8835-009	gamma-BHC (Lindane)					<1.2	BQL	U	120								
8835-009	Heptachlor					<1.2	BQL	U	120								
8835-009	Heptachlor epoxide					<2.4	BQL	U	120								
8835-009	Endosulfan I					<1.2	BQL	U	120								
8835-009	Endrin					<1.2	BQL	U	120								
8835-009	Endosulfan II					<1.2	BQL	U	120								
8835-009	Chlordane					<12	BQL	U	120								
8835-009	Endrin aldehyde					<1.2	BQL	U	120								
8835-009	Endrin ketone					<1.2	BQL	U	120								
8835-009	2,4-D					<6.0	BQL	U	120								
8835-009	Silvex					<6.0	BQL	U	120								
8835-009	2,3,7,8-Tetrachlorodibenzo-p-dioxin					<30	BQL	U	12.0								
8835-010	1,3-Dichlorobenzene					<600	BQL	U	59.8								
8835-010	1,3-Propane sultone					<100	BQL	U	10.0								
8835-010	2-Fluoroacetamide					<100	BQL	U	10.0								
8835-010	3,3'-Dimethoxybenzidine					<100	BQL	U	10.0								
8835-010	4,4'-methylene-bis(2-chloroaniline)					<100	BQL	U	10.0								
8835-010	4,6-Dinitro-2-methylphenol					<600	BQL	U	59.8								
8835-010	4-Aminopyridine					<100	BQL	U	10.0								
8835-010	4-Bromophenyl phenyl ether					<600	BQL	U	59.8								
8835-010	Acetone cyanohydrin					<100	BQL	U	10.0								
8835-010	Benzal chloride					<100	BQL	U	10.0								
8835-010	Benzyl chloride					<100	BQL	U	10.0								
8835-010	Bis(2-chloroethyl)ether					<600	BQL	U	59.8								
8835-010	Bis(2-chloroethoxy)methane					<600	BQL	U	59.8								
8835-010	Bis(2-ethylhexyl)phthalate					<600	BQL	U	59.8								
8835-010	Endothall					<100	BQL	U	10.0								
8835-010	Ethyl carbamate					<100	BQL	U	10.0								
8835-010	Ethylene glycol monoethyl ether					<100	BQL	U	10.0								
8835-010	Ethylenethiourea (2-Imidazolidinethione)					<12	BQL	U	1.2								
8835-010	m-Dinitrobenzene					<600	BQL	U	59.8								
8835-010	Methomyl					<6.0	BQL	U	1.2								
8835-010	MNNG (N-Metyl-N-nitroso-N'-nitroguanidine)					<12	BQL	U	1.2								

COMPARATIVE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-010	N-Nitrosodiphenylamine					<600	BQL	U	59.8								
8835-010	Nicotine					<100	BQL	U	10.0								
8835-010	Phenylthiourea					<6.0	BQL	U	1.2								
8835-010	p-Toluidine					<100	BQL	U	10.0								
8835-010	6-Propyl-2-thiouracil					<100	BQL	U	10.0								
8835-010	Strychnine					<100	BQL	U	10.0								
8835-010	Thioacetamide					<6.0	BQL	U	1.2								
8835-010	Thiofanox					<100	BQL	U	10.0								
8835-010	Thiourea					<6.0	BQL	U	1.2								
8835-010	Toluene-2,4-diamine					<6.0	BQL	U	1.2								
8835-010	Toluene-2,6-diamine					<6.0	BQL	U	1.2								
8835-010	gamma-BHC (Lindane)					<1.2	BQL	U	120								
8835-010	Heptachlor					<1.2	BQL	U	120								
8835-010	Heptachlor epoxide					<2.4	BQL	U	120								
8835-010	Endosulfan I					<1.2	BQL	U	120								
8835-010	Endrin					<1.2	BQL	U	120								
8835-010	Endosulfan II					<1.2	BQL	U	120								
8835-010	Chlordane					<12	BQL	U	120								
8835-010	Endrin aldehyde					<1.2	BQL	U	120								
8835-010	Endrin ketone					<1.2	BQL	U	120								
8835-010	2,4-D					<6.0	BQL	U	120								
8835-010	Silvex					<6.0	BQL	U	120								
8835-010	2,3,7,8-Tetrachlorodibenzo-p-dioxin					<30	BQL	U	12.0								
8835-011	1,3-Dichlorobenzene					<580	BQL	U	58.3								
8835-011	1,3-Propane sultone					<100	BQL	U	10.0								
8835-011	2-Fluoroacetamide					<100	BQL	U	10.0								
8835-011	3,3'-Dimethoxybenzidine					<100	BQL	U	10.0								
8835-011	4,4'-methylene-bis(2-chloroaniline)					<100	BQL	U	10.0								
8835-011	4,6-Dinitro-2-methylphenol					<580	BQL	U	58.3								
8835-011	4-Aminopyridine					<100	BQL	U	10.0								
8835-011	4-Bromophenyl phenyl ether					<580	BQL	U	58.3								
8835-011	Acetone cyanohydrin					<100	BQL	U	10.0								
8835-011	Benzal chloride					<100	BQL	U	10.0								
8835-011	Benzyl chloride					<100	BQL	U	10.0								
8835-011	Bis(2-chloroethyl)ether					<580	BQL	U	58.3								
8835-011	Bis(2-chloroethoxy)methane					<580	BQL	U	58.3								

COMPARATIVE FUELS RESULTS - SVOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-011	Bis(2-ethylhexyl)phthalate					<580	BQL	U	58.3								
8835-011	Endothall					<100	BQL	U	10.0								
8835-011	Ethyl carbamate					<100	BQL	U	10.0								
8835-011	Ethylene glycol monoethyl ether					<100	BQL	U	10.0								
8835-011	Ethylenethiourea (2-Imidazolidinethione)					<12	BQL	U	1.2								
8835-011	m-Dinitrobenzene					<580	BQL	U	58.3								
8835-011	Methomyl					<5.8	BQL	U	1.2								
8835-011	MNNG (N-Metyl-N-nitroso-N'-nitroguanidine)					<12	BQL	U	1.2								
8835-011	N-Nitrosodiphenylamine					<580	BQL	U	58.3								
8835-011	Nicotine					<100	BQL	U	10.0								
8835-011	Phenylthiourea					<5.8	BQL	U	1.2								
8835-011	p-Toluidine					<100	BQL	U	10.0								
8835-011	6-Propyl-2-thiouracil					<100	BQL	U	10.0								
8835-011	Strychnine					<100	BQL	U	10.0								
8835-011	Thioacetamide					<5.8	BQL	U	1.2								
8835-011	Thiofanox					<100	BQL	U	10.0								
8835-011	Thiourea					<5.8	BQL	U	1.2								
8835-011	Toluene-2,4-diamine					<5.8	BQL	U	1.2								
8835-011	Toluene-2,6-diamine					<5.8	BQL	U	1.2								
8835-011	gamma-BHC (Lindane)					<1.2	BQL	U	117								
8835-011	Heptachlor					<1.2	BQL	U	117								
8835-011	Heptachlor epoxide					<2.3	BQL	U	117								
8835-011	Endosulfan I					<1.2	BQL	U	117								
8835-011	Endrin					<1.2	BQL	U	117								
8835-011	Endosulfan II					<1.2	BQL	U	117								
8835-011	Chlordane					<12	BQL	U	117								
8835-011	Endrin aldehyde					<1.2	BQL	U	117								
8835-011	Endrin ketone					<1.2	BQL	U	117								
8835-011	2,4-D					<5.8	BQL	U	117								
8835-011	Silvex					<5.8	BQL	U	117								
8835-011	2,3,7,8-Tetrachlorodibenzo-p-dioxin					<29	BQL	U	11.7								

COMPARABLE FUELS RESULTS - VOC (mg/Kg)

		Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
Sample	Analyte	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-001	1,1,2,2-Tetrachloroethane	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	1,1,2-Trichloroethane	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	1,1-Dichloroethene	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	1,2,3,-Trichloropropane	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	1,2,4-Trichlorobenzene	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	1,2-Dibromo-3-chloropropane	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	1,2-Dibromoethane	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	1,2-Dichlorobenzene	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	1,3-Dichlorobenzene	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	1,4-Dichlorobenzene	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	2-Butanone	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	2-Chloroethylvinyl ether	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Acetonitrile	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Acrolein	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Acrylonitrile	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Allyl chloride	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Benzene	<3300	6400		333	<32	38		3.23	<17	42		1.72	<16		U	1.64
8835-001	Bromoform	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Bromomethane	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Carbon disulfide	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Carbon tetrachloride	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Chlorobenzene	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Chloroform	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Chloromethane	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Chloroprene	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	cis-1,2-Dichloroethene	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	cis-1,3-Dichloropropene	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	cis-1,4-Dichloro-2-butene	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Dibromomethane	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Dichlorodifluoromethane	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Ethyl methacrylate	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Iodomethane	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Isobutanol	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	m,p-Xylene	<6700	44000		333	<65	1200		3.23	<34	560		1.72	<33	60		1.64
8835-001	Methacrylonitrile	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Methyl methacrylate	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Methylene chloride	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	o-Xylene	<3300	17000		333	<32	290		3.23	<17	130		1.72	<16		U	1.64
8835-001	p-Dioxane	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Pentachloroethane	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Propionitrile	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Tetrachloroethene	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Toluene	<3300	50000		333	<32	280		3.23	<17	220		1.72	<16		U	1.64
8835-001	trans-1,2-Dichloroethene	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	trans-1,4-Dichloro-2-butene	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Trichloroethene	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64

COMPARABLE FUELS RESULTS - VOC (mg/Kg)

		Fuel = Gasoline				*Fuel = No.2*				*Fuel = No.4*				*Fuel = No.6*			
Sample	**Analyte**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**
8835-001	Trichlorofluoromethane	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-001	Vinyl Chloride	<3300		U	333	<32		U	3.23	<17		U	1.72	<16		U	1.64
8835-002	1,1,2,2-Tetrachloroethane	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	1,1,2-Trichloroethane	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	1,1-Dichloroethene	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	1,2,3,-Trichloropropane	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	1,2,4-Trichlorobenzene	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	1,2-Dibromo-3-chloropropane	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	1,2-Dibromoethane	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	1,2-Dichlorobenzene	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	1,3-Dichlorobenzene	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	1,4-Dichlorobenzene	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	2-Butanone	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	2-Chloroethylvinyl ether	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Acetonitrile	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Acrolein	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Acrylonitrile	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Allyl chloride	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Benzene	<3200	6200		325	<34	39		3.43					<17		U	1.66
8835-002	Bromoform	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Bromomethane	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Carbon disulfide	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Carbon tetrachloride	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Chlorobenzene	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Chloroform	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Chloromethane	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Chloroprene	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	cis-1,2-Dichloroethene	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	cis-1,3-Dichloropropene	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	cis-1,4-Dichloro-2-butene	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Dibromomethane	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Dichlorodifluoromethane	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Ethyl methacrylate	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Iodomethane	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Isobutanol	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	m,p-Xylene	<6500	43000		325	<69	1200		3.43					<33	320		1.66
8835-002	Methacrylonitrile	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Methyl methacrylate	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Methylene chloride	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	o-Xylene	<3200	17000		325	<34	300		3.43					<17	67		1.66
8835-002	p-Dioxane	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Pentachloroethane	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Propionitrile	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Tetrachloroethene	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Toluene	<3200	49000		325	<34	290		3.43					<17	76		1.66
8835-002	trans-1,2-Dichloroethene	<3200		U	325	<34		U	3.43					<17		U	1.66

COMPARABLE FUELS RESULTS - VOC (mg/Kg)

		Fuel = Gasoline				***Fuel = No.2***				***Fuel = No.4***				***Fuel = No.6***			
Sample	**Analyte**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**
8835-002	trans-1,4-Dichloro-2-butene	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Trichloroethene	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Trichlorofluoromethane	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-002	Vinyl Chloride	<3200		U	325	<34		U	3.43					<17		U	1.66
8835-003	1,1,2,2-Tetrachloroethane	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	1,1,2-Trichloroethane	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	1,1-Dichloroethene	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	1,2,3,-Trichloropropane	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	1,2,4-Trichlorobenzene	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	1,2-Dibromo-3-chloropropane	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	1,2-Dibromoethane	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	1,2-Dichlorobenzene	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	1,3-Dichlorobenzene	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	1,4-Dichlorobenzene	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	2-Butanone	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	2-Chloroethylvinyl ether	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Acetonitrile	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Acrolein	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Acrylonitrile	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Allyl chloride	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Benzene	<3400	6600		339	<33		U	3.29					<16		U	1.61
8835-003	Bromoform	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Bromomethane	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Carbon disulfide	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Carbon tetrachloride	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Chlorobenzene	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Chloroform	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Chloromethane	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Chloroprene	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	cis-1,2-Dichloroethene	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	cis-1,3-Dichloropropene	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	cis-1,4-Dichloro-2-butene	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Dibromomethane	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Dichlorodifluoromethane	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Ethyl methacrylate	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Iodomethane	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Isobutanol	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	m,p-Xylene	<6800	36000		339	<66	500		3.29					<32	300		1.61
8835-003	Methacrylonitrile	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Methyl methacrylate	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Methylene chloride	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	o-Xylene	<3400	13000		339	<33	270		3.29					<16	63		1.61
8835-003	p-Dioxane	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Pentachloroethane	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Propionitrile	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Tetrachloroethene	<3400		U	339	<33		U	3.29					<16		U	1.61

COMPARABLE FUELS RESULTS - VOC (mg/Kg)

		Fuel = Gasoline				***Fuel = No.2***				***Fuel = No.4***				***Fuel = No.6***			
Sample	**Analyte**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**
8835-003	Toluene	<3400	68000		339	<33	160		3.29					<16	76		1.61
8835-003	trans-1,2-Dichloroethene	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	trans-1,4-Dichloro-2-butene	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Trichloroethene	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Trichlorofluoromethane	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-003	Vinyl Chloride	<3400		U	339	<33		U	3.29					<16		U	1.61
8835-004	1,1,2,2-Tetrachloroethane	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	1,1,2-Trichloroethane	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	1,1-Dichloroethene	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	1,2,3,-Trichloropropane	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	1,2,4-Trichlorobenzene	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	1,2-Dibromo-3-chloropropane	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	1,2-Dibromoethane	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	1,2-Dichlorobenzene	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	1,3-Dichlorobenzene	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	1,4-Dichlorobenzene	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	2-Butanone	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	2-Chloroethylvinyl ether	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Acetonitrile	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Acrolein	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Acrylonitrile	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Allyl chloride	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Benzene	<3400	6600		337	<33		U	3.33					<16		U	1.62
8835-004	Bromoform	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Bromomethane	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Carbon disulfide	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Carbon tetrachloride	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Chlorobenzene	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Chloroform	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Chloromethane	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Chloroprene	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	cis-1,2-Dichloroethene	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	cis-1,3-Dichloropropene	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	cis-1,4-Dichloro-2-butene	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Dibromomethane	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Dichlorodifluoromethane	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Ethyl methacrylate	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Iodomethane	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Isobutanol	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	m,p-Xylene	<6700	36000		337	<66	1000		3.33					<32	34		1.62
8835-004	Methacrylonitrile	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Methyl methacrylate	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Methylene chloride	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	o-Xylene	<3400	13000		337	<33	290		3.33					<16		U	1.62
8835-004	p-Dioxane	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Pentachloroethane	<3400		U	337	<33		U	3.33					<16		U	1.62

COMPARABLE FUELS RESULTS - VOC (mg/Kg)

		Fuel = Gasoline				***Fuel = No.2***				***Fuel = No.4***				***Fuel = No.6***			
Sample	**Analyte**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**
8835-004	Propionitrile	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Tetrachloroethene	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Toluene	<3400	69000		337	<33	170		3.33					<16		U	1.62
8835-004	trans-1,2-Dichloroethene	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	trans-1,4-Dichloro-2-butene	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Trichloroethene	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Trichlorofluoromethane	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-004	Vinyl Chloride	<3400		U	337	<33		U	3.33					<16		U	1.62
8835-005	1,1,2,2-Tetrachloroethane	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	1,1,2-Trichloroethane	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	1,1-Dichloroethene	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	1,2,3,-Trichloropropane	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	1,2,4-Trichlorobenzene	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	1,2-Dibromo-3-chloropropane	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	1,2-Dibromoethane	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	1,2-Dichlorobenzene	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	1,3-Dichlorobenzene	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	1,4-Dichlorobenzene	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	2-Butanone	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	2-Chloroethylvinyl ether	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Acetonitrile	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Acrolein	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Acrylonitrile	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Allyl chloride	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Benzene	<3200	5400		326	<32		U	3.25					<16		U	1.57
8835-005	Bromoform	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Bromomethane	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Carbon disulfide	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Carbon tetrachloride	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Chlorobenzene	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Chloroform	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Chloromethane	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Chloroprene	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	cis-1,2-Dichloroethene	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	cis-1,3-Dichloropropene	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	cis-1,4-Dichloro-2-butene	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Dibromomethane	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Dichlorodifluoromethane	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Ethyl methacrylate	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Iodomethane	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Isobutanol	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	m,p-Xylene	<6500	39000		326	<65	360		3.25					<31		U	1.57
8835-005	Methacrylonitrile	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Methyl methacrylate	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Methylene chloride	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	o-Xylene	<3200	14000		326	<32	170		3.25					<16		U	1.57

COMPARABLE FUELS RESULTS - VOC (mg/Kg)

		Fuel = Gasoline				***Fuel = No.2***				***Fuel = No.4***				***Fuel = No.6***			
Sample	**Analyte**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**
8835-005	p-Dioxane	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Pentachloroethane	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Propionitrile	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Tetrachloroethene	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Toluene	<3200	42000		326	<32	130		3.25					<16		U	1.57
8835-005	trans-1,2-Dichloroethene	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	trans-1,4-Dichloro-2-butene	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Trichloroethene	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Trichlorofluoromethane	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-005	Vinyl Chloride	<3200		U	326	<32		U	3.25					<16		U	1.57
8835-006	1,1,2,2-Tetrachloroethane	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	1,1,2-Trichloroethane	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	1,1-Dichloroethene	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	1,2,3,-Trichloropropane	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	1,2,4-Trichlorobenzene	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	1,2-Dibromo-3-chloropropane	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	1,2-Dibromoethane	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	1,2-Dichlorobenzene	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	1,3-Dichlorobenzene	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	1,4-Dichlorobenzene	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	2-Butanone	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	2-Chloroethylvinyl ether	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Acetonitrile	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Acrolein	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Acrylonitrile	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Allyl chloride	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Benzene	<1600	6200		161	<34		U	3.44					<21		U	2.08
8835-006	Bromoform	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Bromomethane	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Carbon disulfide	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Carbon tetrachloride	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Chlorobenzene	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Chloroform	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Chloromethane	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Chloroprene	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	cis-1,2-Dichloroethene	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	cis-1,3-Dichloropropene	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	cis-1,4-Dichloro-2-butene	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Dibromomethane	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Dichlorodifluoromethane	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Ethyl methacrylate	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Iodomethane	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Isobutanol	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	m,p-Xylene	<3200	22000		161	<69	130		3.44					<42	150		2.08
8835-006	Methacrylonitrile	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Methyl methacrylate	<1600		U	161	<34		U	3.44					<21		U	2.08

COMPARABLE FUELS RESULTS - VOC (mg/Kg)

		Fuel = Gasoline				***Fuel = No.2***				***Fuel = No.4***				***Fuel = No.6***			
Sample	**Analyte**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**
8835-006	Methylene chloride	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	o-Xylene	<1600	8300		161	<34	61		3.44					<21	70		2.08
8835-006	p-Dioxane	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Pentachloroethane	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Propionitrile	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Tetrachloroethene	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Toluene	<1600	29000		161	<34	96		3.44					<21	60		2.08
8835-006	trans-1,2-Dichloroethene	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	trans-1,4-Dichloro-2-butene	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Trichloroethene	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Trichlorofluoromethane	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-006	Vinyl Chloride	<1600		U	161	<34		U	3.44					<21		U	2.08
8835-007	1,1,2,2-Tetrachloroethane	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	1,1,2-Trichloroethane	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	1,1-Dichloroethene	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	1,2,3,-Trichloropropane	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	1,2,4-Trichlorobenzene	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	1,2-Dibromo-3-chloropropane	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	1,2-Dibromoethane	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	1,2-Dichlorobenzene	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	1,3-Dichlorobenzene	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	1,4-Dichlorobenzene	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	2-Butanone	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	2-Chloroethylvinyl ether	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Acetonitrile	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Acrolein	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Acrylonitrile	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Allyl chloride	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Benzene	<1700	4500		169	<33		U	3.35					<20		U	1.95
8835-007	Bromoform	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Bromomethane	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Carbon disulfide	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Carbon tetrachloride	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Chlorobenzene	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Chloroform	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Chloromethane	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Chloroprene	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	cis-1,2-Dichloroethene	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	cis-1,3-Dichloropropene	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	cis-1,4-Dichloro-2-butene	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Dibromomethane	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Dichlorodifluoromethane	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Ethyl methacrylate	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Iodomethane	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Isobutanol	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	m,p-Xylene	<3400	56000		169	<67	670		3.35					<39	73		1.95

COMPARABLE FUELS RESULTS - VOC (mg/Kg)

		Fuel = Gasoline				***Fuel = No.2***				***Fuel = No.4***				***Fuel = No.6***			
Sample	**Analyte**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**
8835-007	Methacrylonitrile	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Methyl methacrylate	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Methylene chloride	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	o-Xylene	<1700	12000		169	<33	320		3.35					<20	33		1.95
8835-007	p-Dioxane	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Pentachloroethane	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Propionitrile	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Tetrachloroethene	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Toluene	<1700	32000		169	<33	240		3.35					<20	29		1.95
8835-007	trans-1,2-Dichloroethene	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	trans-1,4-Dichloro-2-butene	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Trichloroethene	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Trichlorofluoromethane	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-007	Vinyl chloride	<1700		U	169	<33		U	3.35					<20		U	1.95
8835-008	1,1,2,2-Tetrachloroethane	<1700		U	170	<33		U	3.35								
8835-008	1,1,2-Trichloroethane	<1700		U	170	<33		U	3.35								
8835-008	1,1-Dichloroethene	<1700		U	170	<33		U	3.35								
8835-008	1,2,3,-Trichloropropane	<1700		U	170	<33		U	3.35								
8835-008	1,2,4-Trichlorobenzene	<1700		U	170	<33		U	3.35								
8835-008	1,2-Dibromo-3-chloropropane	<1700		U	170	<33		U	3.35								
8835-008	1,2-Dibromoethane	<1700		U	170	<33		U	3.35								
8835-008	1,2-Dichlorobenzene	<1700		U	170	<33		U	3.35								
8835-008	1,3-Dichlorobenzene	<1700		U	170	<33		U	3.35								
8835-008	1,4-Dichlorobenzene	<1700		U	170	<33		U	3.35								
8835-008	2-Butanone	<1700		U	170	<33		U	3.35								
8835-008	2-Chloroethylvinyl ether	<1700		U	170	<33		U	3.35								
8835-008	Acetonitrile	<1700		U	170	<33		U	3.35								
8835-008	Acrolein	<1700		U	170	<33		U	3.35								
8835-008	Acrylonitrile	<1700		U	170	<33		U	3.35								
8835-008	Allyl chloride	<1700		U	170	<33		U	3.35								
8835-008	Benzene	<1700	8000		170	<33	42		3.35								
8835-008	Bromoform	<1700		U	170	<33		U	3.35								
8835-008	Bromomethane	<1700		U	170	<33		U	3.35								
8835-008	Carbon disulfide	<1700		U	170	<33		U	3.35								
8835-008	Carbon tetrachloride	<1700		U	170	<33		U	3.35								
8835-008	Chlorobenzene	<1700		U	170	<33		U	3.35								
8835-008	Chloroform	<1700		U	170	<33		U	3.35								
8835-008	Chloromethane	<1700		U	170	<33		U	3.35								
8835-008	Chloroprene	<1700		U	170	<33		U	3.35								
8835-008	cis-1,2-Dichloroethene	<1700		U	170	<33		U	3.35								
8835-008	cis-1,3-Dichloropropene	<1700		U	170	<33		U	3.35								
8835-008	cis-1,4-Dichloro-2-butene	<1700		U	170	<33		U	3.35								
8835-008	Dibromomethane	<1700		U	170	<33		U	3.35								
8835-008	Dichlorodifluoromethane	<1700		U	170	<33		U	3.35								
8835-008	Ethyl methacrylate	<1700		U	170	<33		U	3.35								
8835-008	Iodomethane	<1700		U	170	<33		U	3.35								

COMPARABLE FUELS RESULTS - VOC (mg/Kg)

		Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
Sample	Analyte	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-008	Isobutanol	<1700		U	170	<33		U	3.35								
8835-008	m,p-Xylene	<3400	28000		170	<67	630		3.35								
8835-008	Methacrylonitrile	<1700		U	170	<33		U	3.35								
8835-008	Methyl methacrylate	<1700		U	170	<33		U	3.35								
8835-008	Methylene chloride	<1700		U	170	<33		U	3.35								
8835-008	o-Xylene	<1700	10000		170	<33	280		3.35								
8835-008	p-Dioxane	<1700		U	170	<33		U	3.35								
8835-008	Pentachloroethane	<1700		U	170	<33		U	3.35								
8835-008	Propionitrile	<1700		U	170	<33		U	3.35								
8835-008	Tetrachloroethene	<1700		U	170	<33		U	3.35								
8835-008	Toluene	<1700	34000		170	<33	300		3.35								
8835-008	trans-1,2-Dichloroethene	<1700		U	170	<33		U	3.35								
8835-008	trans-1,4-Dichloro-2-butene	<1700		U	170	<33		U	3.35								
8835-008	Trichloroethene	<1700		U	170	<33		U	3.35								
8835-008	Trichlorofluoromethane	<1700		U	170	<33		U	3.35								
8835-008	Vinyl chloride	<1700		U	170	<33		U	3.35								
8835-009	1,1,2,2-Tetrachloroethane					<34		U	3.37								
8835-009	1,1,2-Trichloroethane					<34		U	3.37								
8835-009	1,1-Dichloroethene					<34		U	3.37								
8835-009	1,2,3,-Trichloropropane					<34		U	3.37								
8835-009	1,2,4-Trichlorobenzene					<34		U	3.37								
8835-009	1,2-Dibromo-3-chloropropane					<34		U	3.37								
8835-009	1,2-Dibromoethane					<34		U	3.37								
8835-009	1,2-Dichlorobenzene					<34		U	3.37								
8835-009	1,3-Dichlorobenzene					<34		U	3.37								
8835-009	1,4-Dichlorobenzene					<34		U	3.37								
8835-009	2-Butanone					<34		U	3.37								
8835-009	2-Chloroethylvinyl ether					<34		U	3.37								
8835-009	Acetonitrile					<34		U	3.37								
8835-009	Acrolein					<34		U	3.37								
8835-009	Acrylonitrile					<34		U	3.37								
8835-009	Allyl chloride					<34		U	3.37								
8835-009	Benzene					<34		U	3.37								
8835-009	Bromoform					<34		U	3.37								
8835-009	Bromomethane					<34		U	3.37								
8835-009	Carbon disulfide					<34		U	3.37								
8835-009	Carbon tetrachloride					<34		U	3.37								
8835-009	Chlorobenzene					<34		U	3.37								
8835-009	Chloroform					<34		U	3.37								
8835-009	Chloromethane					<34		U	3.37								
8835-009	Chloroprene					<34		U	3.37								
8835-009	cis-1,2-Dichloroethene					<34		U	3.37								
8835-009	cis-1,3-Dichloropropene					<34		U	3.37								
8835-009	cis-1,4-Dichloro-2-butene					<34		U	3.37								
8835-009	Dibromomethane					<34		U	3.37								
8835-009	Dichlorodifluoromethane					<34		U	3.37								

COMPARABLE FUELS RESULTS - VOC (mg/Kg)

		Fuel = Gasoline				***Fuel = No.2***				***Fuel = No.4***				***Fuel = No.6***			
Sample	**Analyte**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**
8835-009	Ethyl methacrylate					<34		U	3.37								
8835-009	Iodomethane					<34		U	3.37								
8835-009	Isobutanol					<34		U	3.37								
8835-009	m,p-Xylene					<67	420		3.37								
8835-009	Methacrylonitrile					<34		U	3.37								
8835-009	Methyl methacrylate					<34		U	3.37								
8835-009	Methylene chloride					<34		U	3.37								
8835-009	o-Xylene					<34	180		3.37								
8835-009	p-Dioxane					<34		U	3.37								
8835-009	Pentachloroethane					<34		U	3.37								
8835-009	Propionitrile					<34		U	3.37								
8835-009	Tetrachloroethene					<34		U	3.37								
8835-009	Toluene					<34	220		3.37								
8835-009	trans-1,2-Dichloroethene					<34		U	3.37								
8835-009	trans-1,4-Dichloro-2-butene					<34		U	3.37								
8835-009	Trichloroethene					<34		U	3.37								
8835-009	Trichlorofluoromethane					<34		U	3.37								
8835-009	Vinyl Chloride					<34		U	3.37								
8835-010	1,1,2,2-Tetrachloroethane					<32		U	3.23								
8835-010	1,1,2-Trichloroethane					<32		U	3.23								
8835-010	1,1-Dichloroethene					<32		U	3.23								
8835-010	1,2,3,-Trichloropropane					<32		U	3.23								
8835-010	1,2,4-Trichlorobenzene					<32		U	3.23								
8835-010	1,2-Dibromo-3-chloropropane					<32		U	3.23								
8835-010	1,2-Dibromoethane					<32		U	3.23								
8835-010	1,2-Dichlorobenzene					<32		U	3.23								
8835-010	1,3-Dichlorobenzene					<32		U	3.23								
8835-010	1,4-Dichlorobenzene					<32		U	3.23								
8835-010	2-Butanone					<32		U	3.23								
8835-010	2-Chloroethylvinyl ether					<32		U	3.23								
8835-010	Acetonitrile					<32		U	3.23								
8835-010	Acrolein					<32		U	3.23								
8835-010	Acrylonitrile					<32		U	3.23								
8835-010	Allyl chloride					<32		U	3.23								
8835-010	Benzene					<32		U	3.23								
8835-010	Bromoform					<32		U	3.23								
8835-010	Bromomethane					<32		U	3.23								
8835-010	Carbon disulfide					<32		U	3.23								
8835-010	Carbon tetrachloride					<32		U	3.23								
8835-010	Chlorobenzene					<32		U	3.23								
8835-010	Chloroform					<32		U	3.23								
8835-010	Chloromethane					<32		U	3.23								
8835-010	Chloroprene					<32		U	3.23								
8835-010	cis-1,2-Dichloroethene					<32		U	3.23								
8835-010	cis-1,3-Dichloropropene					<32		U	3.23								
8835-010	cis-1,4-Dichloro-2-butene					<32		U	3.23								

COMPARABLE FUELS RESULTS - VOC (mg/Kg)

		Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
Sample	Analyte	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-010	Dibromomethane					<32		U	3.23								
8835-010	Dichlorodifluoromethane					<32		U	3.23								
8835-010	Ethyl methacrylate					<32		U	3.23								
8835-010	Iodomethane					<32		U	3.23								
8835-010	Isobutanol					<32		U	3.23								
8835-010	m,p-Xylene					<65	410		3.23								
8835-010	Methacrylonitrile					<32		U	3.23								
8835-010	Methyl methacrylate					<32		U	3.23								
8835-010	Methylene chloride					<32		U	3.23								
8835-010	o-Xylene					<32	180		3.23								
8835-010	p-Dioxane					<32		U	3.23								
8835-010	Pentachloroethane					<32		U	3.23								
8835-010	Propionitrile					<32		U	3.23								
8835-010	Tetrachloroethene					<32		U	3.23								
8835-010	Toluene					<32	170		3.23								
8835-010	trans-1,2-Dichloroethene					<32		U	3.23								
8835-010	trans-1,4-Dichloro-2-butene					<32		U	3.23								
8835-010	Trichloroethene					<32		U	3.23								
8835-010	Trichlorofluoromethane					<32		U	3.23								
8835-010	Vinyl chloride					<32		U	3.23								
8835-011	1,1,2,2-Tetrachloroethane					<39		U	3.92								
8835-011	1,1,2-Trichloroethane					<39		U	3.92								
8835-011	1,1-Dichloroethene					<39		U	3.92								
8835-011	1,2,3,-Trichloropropane					<39		U	3.92								
8835-011	1,2,4-Trichlorobenzene					<39		U	3.92								
8835-011	1,2-Dibromo-3-chloropropane					<39		U	3.92								
8835-011	1,2-Dibromoethane					<39		U	3.92								
8835-011	1,2-Dichlorobenzene					<39		U	3.92								
8835-011	1,3-Dichlorobenzene					<39		U	3.92								
8835-011	1,4-Dichlorobenzene					<39		U	3.92								
8835-011	2-Butanone					<39		U	3.92								
8835-011	2-Chloroethylvinyl ether					<39		U	3.92								
8835-011	Acetonitrile					<39		U	3.92								
8835-011	Acrolein					<39		U	3.92								
8835-011	Acrylonitrile					<39		U	3.92								
8835-011	Allyl chloride					<39		U	3.92								
8835-011	Benzene					<39	75		3.92								
8835-011	Bromoform					<39		U	3.92								
8835-011	Bromomethane					<39		U	3.92								
8835-011	Carbon disulfide					<39		U	3.92								
8835-011	Carbon tetrachloride					<39		U	3.92								
8835-011	Chlorobenzene					<39		U	3.92								
8835-011	Chloroform					<39		U	3.92								
8835-011	Chloromethane					<39		U	3.92								
8835-011	Chloroprene					<39		U	3.92								
8835-011	cis-1,2-Dichloroethene					<39		U	3.92								

COMPARABLE FUELS RESULTS - VOC (mg/Kg)

		Fuel = Gasoline				*Fuel = No.2*				*Fuel = No.4*				*Fuel = No.6*			
Sample	**Analyte**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**
8835-011	cis-1,3-Dichloropropene					<39		U	3.92								
8835-011	cis-1,4-Dichloro-2-butene					<39		U	3.92								
8835-011	Dibromomethane					<39		U	3.92								
8835-011	Dichlorodifluoromethane					<39		U	3.92								
8835-011	Ethyl methacrylate					<39		U	3.92								
8835-011	Iodomethane					<39		U	3.92								
8835-011	Isobutanol					<39		U	3.92								
8835-011	m,p-Xylene					<78	900		3.92								
8835-011	Methacrylonitrile					<39		U	3.92								
8835-011	Methyl methacrylate					<39		U	3.92								
8835-011	Methylene chloride					<39		U	3.92								
8835-011	o-Xylene					<39	460		3.92								
8835-011	p-Dioxane					<39		U	3.92								
8835-011	Pentachloroethane					<39		U	3.92								
8835-011	Propionitrile					<39		U	3.92								
8835-011	Tetrachloroethene					<39		U	3.92								
8835-011	Toluene					<39	380		3.92								
8835-011	trans-1,2-Dichloroethene					<39		U	3.92								
8835-011	trans-1,4-Dichloro-2-butene					<39		U	3.92								
8835-011	Trichloroethene					<39		U	3.92								
8835-011	Trichlorofluoromethane					<39		U	3.92								
8835-011	Vinyl Chloride					<39		U	3.92								

COMPARATIVE FUELS RESULTS - VOC (mg/Kg)

Sample	Analyte	***Fuel = Gasoline***				***Fuel = No.2***				***Fuel = No.4***				***Fuel = No.6***			
		Q.L.	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**	**Q.L.**	**Quant-itation**	**Code**	**D.F.**
8835-001	Allyl alcohol	<1300	BQL	U	134	<29	BQL	U	2.9	<29	BQL	U	2.9	<25	BQL	U	2.5
8835-001	Benzenethiol	<1300	BQL	U	134	<29	BQL	U	2.9	<29	BQL	U	2.9	<25	BQL	U	2.5
8835-001	2-Nitropropane	<1300	BQL	U	134	<29	BQL	U	2.9	<29	BQL	U	2.9	<25	BQL	U	2.5
8835-001	1,2-Dichloroethane	<3300	BQL	U	333	<32	BQL	U	3.2	<17	BQL	U	1.7	<16	BQL	U	1.6
8835-001	1,2-Dichloropropane	<3300	BQL	U	333	<32	BQL	U	3.2	<17	BQL	U	1.7	<16	BQL	U	1.6
8835-001	trans-1,3-Dichloropropene	<3300	BQL	U	333	<32	BQL	U	3.2	<17	BQL	U	1.7	<16	BQL	U	1.6
8835-001	1,3-Dichloro-2-propanol	<1300	BQL	U	134	<29	BQL	U	2.9	<29	BQL	U	2.9	<25	BQL	U	2.5
8835-001	Epichlorohydrin	<1300	BQL	U	134	<29	BQL	U	2.9	<29	BQL	U	2.9	<25	BQL	U	2.5
8835-001	1,1-Dichloroethane	<3300	BQL	U	333	<32	BQL	U	3.2	<17	BQL	U	1.7	<16	BQL	U	1.6
8835-001	1,1,1-Trichloroethane	<3300	BQL	U	333	<32	BQL	U	3.2	<17	BQL	U	1.7	<16	BQL	U	1.6
8835-001	Propargyl alcohol	<1300	BQL	U	134	<29	BQL	U	2.9	<29	BQL	U	2.9	<25	BQL	U	2.5
8835-002	Allyl alcohol	<1300	BQL	U	133	<29	BQL	U	2.9					<25	BQL	U	2.5
8835-002	Benzenethiol	<1300	BQL	U	133	<29	BQL	U	2.9					<25	BQL	U	2.5
8835-002	2-Nitropropane	<1300	BQL	U	133	<29	BQL	U	2.9					<25	BQL	U	2.5
8835-002	1,2-Dichloroethane	<3200	BQL	U	325	<34	BQL	U	3.4					<17	BQL	U	1.7
8835-002	1,2-Dichloropropane	<3200	BQL	U	325	<34	BQL	U	3.4					<17	BQL	U	1.7
8835-002	trans-1,3-Dichloropropene	<3200	BQL	U	325	<34	BQL	U	3.4					<17	BQL	U	1.7
8835-002	1,3-Dichloro-2-propanol	<1300	BQL	U	133	<29	BQL	U	2.9					<25	BQL	U	2.5
8835-002	Epichlorohydrin	<1300	BQL	U	133	<29	BQL	U	2.9					<25	BQL	U	2.5
8835-002	1,1-Dichloroethane	<3200	BQL	U	325	<34	BQL	U	3.4					<17	BQL	U	1.7
8835-002	1,1,1-Trichloroethane	<3200	BQL	U	325	<34	BQL	U	3.4					<17	BQL	U	1.7
8835-002	Propargyl alcohol	<1300	BQL	U	133	<29	BQL	U	2.9					<25	BQL	U	2.5
8835-003	Allyl alcohol	<1300	BQL	U	134	<30	BQL	U	3.0					<25	BQL	U	2.5
8835-003	Benzenethiol	<1300	BQL	U	134	<30	BQL	U	3.0					<25	BQL	U	2.5
8835-003	2-Nitropropane	<1300	BQL	U	134	<30	BQL	U	3.0					<25	BQL	U	2.5
8835-003	1,2-Dichloroethane	<3400	BQL	U	339	<33	BQL	U	3.3					<16	BQL	U	1.6
8835-003	1,2-Dichloropropane	<3400	BQL	U	339	<33	BQL	U	3.3					<16	BQL	U	1.6
8835-003	trans-1,3-Dichloropropene	<3400	BQL	U	339	<33	BQL	U	3.3					<16	BQL	U	1.6
8835-003	1,3-Dichloro-2-propanol	<1300	BQL	U	134	<30	BQL	U	3.0					<25	BQL	U	2.5
8835-003	Epichlorohydrin	<1300	BQL	U	134	<30	BQL	U	3.0					<25	BQL	U	2.5
8835-003	1,1-Dichloroethane	<3400	BQL	U	339	<33	BQL	U	3.3					<16	BQL	U	1.6
8835-003	1,1,1-Trichloroethane	<3400	BQL	U	339	<33	BQL	U	3.3					<16	BQL	U	1.6
8835-003	Propargyl alcohol	<1300	BQL	U	134	<30	BQL	U	3.0					<25	BQL	U	2.5
8835-004	Allyl alcohol	<1300	BQL	U	133	<30	BQL	U	3.0					<25	BQL	U	2.5
8835-004	Benzenethiol	<1300	BQL	U	133	<30	BQL	U	3.0					<25	BQL	U	2.5
8835-004	2-Nitropropane	<1300	BQL	U	133	<30	BQL	U	3.0					<25	BQL	U	2.5
8835-004	1,2-Dichloroethane	<3400	BQL	U	337	<33	BQL	U	3.3					<16	BQL	U	1.6

COMPARATIVE FUELS RESULTS - VOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-004	1,2-Dichloropropane	<3400	BQL	U	337	<33	BQL	U	3.3					<16	BQL	U	1.6
8835-004	trans-1,3-Dichloropropene	<3400	BQL	U	337	<33	BQL	U	3.3					<16	BQL	U	1.6
8835-004	1,3-Dichloro-2-propanol	<1300	BQL	U	133	<30	BQL	U	3.0					<25	BQL	U	2.5
8835-004	Epichlorohydrin	<1300	BQL	U	133	<30	BQL	U	3.0					<25	BQL	U	2.5
8835-004	1,1-Dichloroethane	<3400	BQL	U	337	<33	BQL	U	3.3					<16	BQL	U	1.6
8835-004	1,1,1-Trichloroethane	<3400	BQL	U	337	<33	BQL	U	3.3					<16	BQL	U	1.6
8835-004	Propargyl alcohol	<1300	BQL	U	133	<30	BQL	U	3.0					<25	BQL	U	2.5
8835-005	Allyl alcohol	<1300	BQL	U	134	<30	BQL	U	3.0					<25	BQL	U	2.5
8835-005	Benzenethiol	<1300	BQL	U	134	<30	BQL	U	3.0					<25	BQL	U	2.5
8835-005	2-Nitropropane	<1300	BQL	U	134	<30	BQL	U	3.0					<25	BQL	U	2.5
8835-005	1,2-Dichloroethane	<3200	BQL	U	326	<32	BQL	U	3.3					<16	BQL	U	1.6
8835-005	1,2-Dichloropropane	<3200	BQL	U	326	<32	BQL	U	3.3					<16	BQL	U	1.6
8835-005	trans-1,3-Dichloropropene	<3200	BQL	U	326	<32	BQL	U	3.3					<16	BQL	U	1.6
8835-005	1,3-Dichloro-2-propanol	<1300	BQL	U	134	<30	BQL	U	3.0					<25	BQL	U	2.5
8835-005	Epichlorohydrin	<1300	BQL	U	134	<30	BQL	U	3.0					<25	BQL	U	2.5
8835-005	1,1-Dichloroethane	<3200	BQL	U	326	<32	BQL	U	3.3					<16	BQL	U	1.6
8835-005	1,1,1-Trichloroethane	<3200	BQL	U	326	<32	BQL	U	3.3					<16	BQL	U	1.6
8835-005	Propargyl alcohol	<1300	BQL	U	134	<30	BQL	U	3.0					<25	BQL	U	2.5
8835-006	Allyl alcohol	<1400	BQL	U	141	<29	BQL	U	2.9					<26	BQL	U	2.6
8835-006	Benzenethiol	<1400	BQL	U	141	<29	BQL	U	2.9					<26	BQL	U	2.6
8835-006	2-Nitropropane	<1400	BQL	U	141	<29	BQL	U	2.9					<26	BQL	U	2.6
8835-006	1,2-Dichloroethane	<1600	BQL	U	161	<34	BQL	U	3.4					<21	BQL	U	2.1
8835-006	1,2-Dichloropropane	<1600	BQL	U	161	<34	BQL	U	3.4					<21	BQL	U	2.1
8835-006	trans-1,3-Dichloropropene	<1600	BQL	U	161	<34	BQL	U	3.4					<21	BQL	U	2.1
8835-006	1,3-Dichloro-2-propanol	<1400	BQL	U	141	<29	BQL	U	2.9					<26	BQL	U	2.6
8835-006	Epichlorohydrin	<1400	BQL	U	141	<29	BQL	U	2.9					<26	BQL	U	2.6
8835-006	1,1-Dichloroethane	<1600	BQL	U	161	<34	BQL	U	3.4					<21	BQL	U	2.1
8835-006	1,1,1-Trichloroethane	<1600	BQL	U	161	<34	BQL	U	3.4					<21	BQL	U	2.1
8835-006	Propargyl alcohol	<1400	BQL	U	141	<29	BQL	U	2.9					<26	BQL	U	2.6
8835-007	Allyl alcohol	<1400	BQL	U	137	<29	BQL	U	2.9					<25	BQL	U	2.5
8835-007	Benzenethiol	<1400	BQL	U	137	<29	BQL	U	2.9					<25	BQL	U	2.5
8835-007	2-Nitropropane	<1400	BQL	U	137	<29	BQL	U	2.9					<25	BQL	U	2.5
8835-007	1,2-Dichloroethane	<1700	BQL	U	170	<33	BQL	U	3.3					<20	BQL	U	2.0
8835-007	1,2-Dichloropropane	<1700	BQL	U	170	<33	BQL	U	3.3					<20	BQL	U	2.0
8835-007	trans-1,3-Dichloropropene	<1700	BQL	U	170	<33	BQL	U	3.3					<20	BQL	U	2.0
8835-007	1,3-Dichloro-2-propanol	<1400	BQL	U	137	<29	BQL	U	2.9					<25	BQL	U	2.5
8835-007	Epichlorohydrin	<1400	BQL	U	137	<29	BQL	U	2.9					<25	BQL	U	2.5

COMPARATIVE FUELS RESULTS - VOC (mg/Kg)

Sample	Analyte	Fuel = Gasoline				Fuel = No.2				Fuel = No.4				Fuel = No.6			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-007	1,1-Dichloroethane	<1700	BQL	U	170	<33	BQL	U	3.3					<20	BQL	U	2.0
8835-007	1,1,1-Trichloroethane	<1700	BQL	U	170	<33	BQL	U	3.3					<20	BQL	U	2.0
8835-007	Propargyl alcohol	<1400	BQL	U	137	<29	BQL	U	2.9					<25	BQL	U	2.5
8835-008	Allyl alcohol	<1400	BQL	U	139	<30	BQL	U	3.0								
8835-008	Benzenethiol	<1400	BQL	U	139	<30	BQL	U	3.0								
8835-008	2-Nitropropane	<1400	BQL	U	139	<30	BQL	U	3.0								
8835-008	1,2-Dichloroethane	<1700	BQL	U	170	<33	BQL	U	3.3								
8835-008	1,2-Dichloropropane	<1700	BQL	U	170	<33	BQL	U	3.3								
8835-008	trans-1,3-Dichloropropene	<1700	BQL	U	170	<33	BQL	U	3.3								
8835-008	1,3-Dichloro-2-propanol	<1400	BQL	U	139	<30	BQL	U	3.0								
8835-008	Epichlorohydrin	<1400	BQL	U	139	<30	BQL	U	3.0								
8835-008	1,1-Dichloroethane	<1700	BQL	U	170	<33	BQL	U	3.3								
8835-008	1,1,1-Trichloroethane	<1700	BQL	U	170	<33	BQL	U	3.3								
8835-008	Propargyl alcohol	<1400	BQL	U	139	<30	BQL	U	3.0								
8835-009	Allyl alcohol					<30	BQL	U	3.0								
8835-009	Benzenethiol					<30	BQL	U	3.0								
8835-009	2-Nitropropane					<30	BQL	U	3.0								
8835-009	1,2-Dichloroethane					<34	BQL	U	3.4								
8835-009	1,2-Dichloropropane					<34	BQL	U	3.4								
8835-009	trans-1,3-Dichloropropene					<34	BQL	U	3.4								
8835-009	1,3-Dichloro-2-propanol					<30	BQL	U	3.0								
8835-009	Epichlorohydrin					<30	BQL	U	3.0								
8835-009	1,1-Dichloroethane					<34	BQL	U	3.4								
8835-009	1,1,1-Trichloroethane					<34	BQL	U	3.4								
8835-009	Propargyl alcohol					<30	BQL	U	3.0								
8835-010	Allyl alcohol					<30	BQL	U	3.0								
8835-010	Benzenethiol					<30	BQL	U	3.0								
8835-010	2-Nitropropane					<30	BQL	U	3.0								
8835-010	1,2-Dichloroethane					<32	BQL	U	3.2								
8835-010	1,2-Dichloropropane					<32	BQL	U	3.2								
8835-010	trans-1,3-Dichloropropene					<32	BQL	U	3.2								
8835-010	1,3-Dichloro-2-propanol					<30	BQL	U	3.0								
8835-010	Epichlorohydrin					<30	BQL	U	3.0								
8835-010	1,1-Dichloroethane					<32	BQL	U	3.2								
8835-010	1,1,1-Trichloroethane					<32	BQL	U	3.2								
8835-010	Propargyl alcohol					<30	BQL	U	3.0								
8835-011	Allyl alcohol					<29	BQL	U	2.9								

COMPARATIVE FUELS RESULTS - VOC (mg/Kg)

Sample	Analyte	*Fuel = Gasoline*				*Fuel = No.2*				*Fuel = No.4*				*Fuel = No.6*			
		Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.	Q.L.	Quant-itation	Code	D.F.
8835-011	Benzenethiol					<29	BQL	U	2.9								
8835-011	2-Nitropropane					<29	BQL	U	2.9								
8835-011	1,2-Dichloroethane					<39	BQL	U	3.9								
8835-011	1,2-Dichloropropane					<39	BQL	U	3.9								
8835-011	trans-1,3-Dichloropropene					<39	BQL	U	3.9								
8835-011	1,3-Dichloro-2-propanol					<29	BQL	U	2.9								
8835-011	Epichlorohydrin					<29	BQL	U	2.9								
8835-011	1,1-Dichloroethane					<39	BQL	U	3.9								
8835-011	1,1,1-Trichloroethane					<39	BQL	U	3.9								
8835-011	Propargyl alcohol					<29	BQL	U	2.9								

COMPARABLE FUELS RESULTS - TOTAL AROMATIC HYDROCARBONS

Sample	Analyte	Fuel = Gasoline		Fuel = No.2		Fuel = No.4		Fuel = No.6	
		Quant-itation	DF	Quant-itation	DF	Quant-itation	DF	Quant-itation	DF
8835-001	Total Aromatic Hydrocarbons (Weight Percent)	15.6	1.0	2.78	1.0	0.97	1.0	0.37	1.0
8835-002	Total Aromatic Hydrocarbons (Weight Percent)	15.5	1.0	2.95	1.0			1.4	1.0
8835-003	Total Aromatic Hydrocarbons (Weight Percent)	16.9	1.0	1.53	1.0			1.42	1.0
8835-004	Total Aromatic Hydrocarbons (Weight Percent)	17.2	1.0	2.06	1.0			0.36	1.0
8835-005	Total Aromatic Hydrocarbons (Weight Percent)	12.6	1.0	2.19	1.0			0.41	1.0
8835-006	Total Aromatic Hydrocarbons (Weight Percent)	8.1	1.0	0.66	1.0			2.99	1.0
8835-007	Total Aromatic Hydrocarbons (Weight Percent)	12.9	1.0	5.24	1.0			0.85	1.0
8835-008	Total Aromatic Hydrocarbons (Weight Percent)	10.5	1.0	1.36	1.0				
8835-009	Total Aromatic Hydrocarbons (Weight Percent)			1.29	1.0				
8835-010	Total Aromatic Hydrocarbons (Weight Percent)			1.42	1.0				
8835-011	Total Aromatic Hydrocarbons (Weight Percent)			1.22	1.0				
8835-001	Total Polynuclear Aromatic Hydrocarbons (Weight Percent)	0.7	1.0	2.9	1.0	1.0	1.0	0.39	1.0
8835-002	Total Polynuclear Aromatic Hydrocarbons (Weight Percent)	0.7	1.0	3.09	1.0			1.5	1.0
8835-003	Total Polynuclear Aromatic Hydrocarbons (Weight Percent)	0.8	1.0	1.52	1.0			1.52	1.0
8835-004	Total Polynuclear Aromatic Hydrocarbons (Weight Percent)	0.9	1.0	2.08	1.0			0.42	1.0
8835-005	Total Polynuclear Aromatic Hydrocarbons (Weight Percent)	0.3	1.0	2.35	1.0			0.49	1.0
8835-006	Total Polynuclear Aromatic Hydrocarbons (Weight Percent)	0.3	1.0	0.7	1.0			3.15	1.0
8835-007	Total Polynuclear Aromatic Hydrocarbons (Weight Percent)	0.6	1.0	5.47	1.0			0.89	1.0
8835-008	Total Polynuclear Aromatic Hydrocarbons (Weight Percent)	0.6	1.0	1.41	1.0				
8835-009	Total Polynuclear Aromatic Hydrocarbons (Weight Percent)			1.36	1.0				
8835-010	Total Polynuclear Aromatic Hydrocarbons (Weight Percent)			1.5	1.0				
8835-011	Total Polynuclear Aromatic Hydrocarbons (Weight Percent)			1.22	1.0				

APPENDIX C

DOCUMENTATION OF EPA DISCUSSIONS WITH TUV

<u>Conference Call with TÜV - Dr. Jockel, May 14, 1998</u>

<u>Purpose</u> -- Provide background briefing to obtain technical input and guidance on EPA Particulate CEMS program from Dr. Wolfgang Jockel of TÜV-Rheinland, Germany.

1. Credentials of Dr. Wolfgang Jockel

   TÜV - Rheinland has been the recognized worldwide authority on Particulate CEMS (referred to as "dust monitors" in Europe) for the past 3 decades. Dr. Wolfgang Jockel is the Leader of their CEMS group. Dr. Jockel will forward a copy of his resume for the project file.

2. Review of EPA Particulate CEMS program status relative to same as practiced in Germany

   2a. Statistical acceptance criteria: correlation coefficient, confidence and tolerance interval.

   Dr. Jockel explained that they have no firm criteria for setting fixed minimum values for these criteria; these values are computed and reviewed for their variation and range; and factors other than particulate CEMS performance drive the values for these criteria, such as reference method data quality, sampling location, and correlation range and particulate characteristics.

   In the December 1997 Notice of Data Availability, EPA proposed setting minimum data acceptance criteria for the correlation coefficient, confidence interval, and tolerance interval. Values for the two intervals would be calculated at either the emission limit or the maximum level measured in the correlation test, whichever is more appropriate.

2b. Suitability tests

Dr. Jockel clarified that under the German regulations each particulate CEMS monitor type undergoes laboratory testing and a suitability test (field test over several months). Instrument testing includes a pair of identical monitors and ongoing plausibility checks, such as daily drift checks and periodical checks of any other critical measurements (e.g., sample flowrate). Correlation tests with comparison to reference method measurements are made over the available range of emissions. Oftentimes the available particulate range is limited. This limitation makes it very important to find the "zero point" of the instrument in order to develop a correlation relation. The zero point may involve instrument removal from its sampling location.

Relative to plausibility testing in the EPA demonstration program -- Two light scattering particulate CEMS (Durag and Environmental Systems Corp. [ESC]) performed automatic daily zero and span drift checks, while the other three had zero and span drift checks performed manually at least every two weeks. Sample flow checks were made on the Emissions SA Beta-gauge but were not made on the Verewa Beta-gauge or the Sigrist light-scattering monitors. Drift checks performed manually on the Sigrist showed < 2% drift. Drift checks performed manually on the two Beta-gauges showed high variation due to apparent moisture adsorption (from the cooling tower below the sampling location) on the vendor supplied foils/wedges.

2c. Data availability

EPA's tentative approach is to set a 90% minimum requirement initially, but may tighten or revisit later. Further clarification on sub-issues, such as whether to include normal scheduled maintenance, has not yet been addressed. Plans are to apply hourly block averaging to consist of four15-minute readings; time periods were set for 15 minutes to accommodate Beta-gauge. Currently a 6-hour rolling block average with hourly updates is being considered. Setting a minimum of at least two 15-minute periods in a hourly block period is also being assessed.

Dr. Jockel explained that TÜV's suitability test criterion is set at 95% data availability. Later a 90% data availability is set; maintenance during scheduled periods is disregarded. For example, the Sigrist has a maintenance interval of two to four weeks. He clarified that the German regulations involve 30 minute block periods as their unit measuring time period. At least 2/3 of the time, or 20 minutes of the 30 minute period, valid data is to be reported;

however, exceptions are allowed. Response times are 200 seconds for achieving a 90% value.

2d. Accounting for measurement uncertainty and error

Dr. Jockel clarified that the German regulations use the emission limit plus the site-specific determined uncertainty level as the level not-to-exceed. Also, the exactness of the particulate CEMS correlation comes back to any uncertainty in the manual particulate method. The TÜV standard practice is to use paired reference method trains to account for measurement error or uncertainty. Gas flow character is also important; as an example, very often they are forced to use two CEMS on large stacks to provide adequate measurement. Under the emerging European Community directive, they are setting confidence interval specific for each pollutant, with 25% being a common level set for many pollutants.

EPA accounts for measurement uncertainty, but in a different way; the emission limit level is set with consideration of the measurement method's uncertainty. Likewise for assuring good quality data, EPA is requiring, facilities to use paired reference method trains for particulate CEMS correlation tests.

2e. Correlation tests, auxiliary data, re-correlation frequency, and related provisions

EPA is proposing a minimum of 15 valid runs over the available range of facility emissions for correlation tests. As the particulate CEMS values are correlated appropriately with the CEMS analysis conditions, measurements for the auxiliary data (typically oxygen, moisture, and temperature) are being planned in order to convert the particulate CEMS raw data into units of the standard, mg/dscm at 7% O_2. Oxygen CEMS are already required for all hazardous waste combustors (HWCs). For many HWCs, monitoring for moisture will be achieved by using the saturation temperature at the wet scrubber system exhaust location. Moisture monitoring approaches are still being evaluated for others; considerations include using a conservative assumption of the moisture level be made, or a moisture CEMS could be applied at the option of the facility. These auxiliary and particulate CEMS data will be handled by the data logger.

The EPA has proposed to allow extrapolation of data up to 125% of the correlation range (that is, 25% higher than the particulate level measured), but to require additional tests to capture the high-end data into the correlation if there are much data beyond that level. Re-correlation frequency is under consideration and will be set somewhere between 1½ to 5 years. And if there are significant changes in process or air pollution control (APC) equipment, a new correlation test is required.

Dr. Jockel clarified that many of their protocols and requirements for the above aspects are identical, including: 15 runs over the available range per correlation test, reference method data correlations to monitor appropriate analysis conditions, equations for calculating data acceptance criteria, as well as use and handling of auxiliary data. However, their re-correlation frequency is set for every 3 years.

Rather interestingly, TÜV found the 3-year correlation frequency to be necessary because in certain instances it was common that a different correlation relation was developed in re-correlation nearly every time (i.e., every 3 years) for light-scattering particulate CEMS. This was especially prevalent for facilities with electrostatic precipitators (ESPs), but frequently occurred with baghouses and wet scrubbers. For ESPs TÜV explained the shifts in correlation relations as likely due to changes in particle size distribution. For the others, they attribute the correlation relation changes to retrofitting add-on APC devices that are installed during the interim in response to stricter emission standards. Many European waste incinerator facilities were originally controlled with ESPs and have had to retrofit add-on scrubbers to meet new emission standards. Since most of the recent add-on APCDs were installed in the 1992 - 1996 period, now they are seeing fewer changes in particle size distribution from these same waste incineration facilities due to stability in APC configurations and emission control performance. In contrast, correlation curves from beta-gauge particulate CEMS are generally consistent upon re-correlation, with the exception for facilities with highly varying levels of aluminum in their particulate.

During correlation tests, TÜV does not encourage re-correlation testing to be performed repeatedly at the same particulate levels because of the limited added-value. If the testing organization cannot influence the facility to adjust its emissions over a wide range, which is not unusual, the testers accept and report whatever data is obtained. It is recognized that such data will limit the statistical validity of the test results. Zero points are typically used to support data of limited concentration range.

2f. Impact of Particulate CEMS

Dr. Jockel explained that initially there was considerable resistance and reluctance toward the advent of particulate CEMS. However, these CEMS allowed facility personnel to better define what process and APC conditions affected particulate emissions and how to reduce emissions. Furthermore, particulate CEMS helped to reduce variations in plant operations between the different styles of process operators. Review of the particulate monitor emission data clearly showed which operating styles were the most emission-effective. And likewise, APC vendors have benefitted from the new level of information produced by these monitors.

Conference Call with TÜV - Dr. Jockel, June 23, 1998

Purpose -- To obtain technical input and guidance on Eli Lilly Particulate CEMS Phase 1 Data.

Dr. Jockel's expertise was sought in the evaluation of the preliminary data produced from the Eli Lilly Particulate CEMS program. The concept (new to us) of repeatability was introduced and explained. A summary of his (on-going) evaluation of the data from the first 54 runs follows below. His evaluation is contained in 3 Excel files e-mailed to EPA on June 22:

- CAL. EVALUATION.xls
- DATA EER-TÜV.xls
- REPEATABILITY.xls

1. General conclusions from evaluating the preliminary Lilly data:

Zero points must be included (added) in the data base for a valid correlation curve to be developed; without zero points, there is insufficient range in the data to base a curve.

There is no evidence of a time-based behavior in the Sigrist data (i.e., data is time-independent). When the data are broken down into 3 campaigns of at least 15 runs each, the slopes of the correlation relation for each data set come close together. It appears that the data set may contain up to 3 outliers, but one would expect a small percentage of natural events to occur and produce a few outliers.

2. Staightforward evaluation of Lilly data

Dr. Jockel then explained the steps and reasoning of his evaluation:

- Develop a correlation curve from the particulate CEMS data (x axis) and the average of the paired Method 5i data (y axis).

- Focus on the criterion of the correlation coefficient, "r" as the credibility basis of the correlation.

- Due to a small range and from normal practice in Germany, add zero points to the correlation data.

- Look to see if there is an indication of a time-based behavior in the correlation relation. If the instrument were drifting or experiencing occasional problems, there would be a time-related behavior pattern.

- Because there are more than three times the normal number of correlation runs, divide the data set of 54 runs into three distinct data sets.

- For these data sets, focus on and compare the slopes of the linear correlation equations; if the slopes change, then there is a change in the performance of the particulate CEMS. In these three data sets, the slopes are quite similar to each other, especially if the obvious outliers are discarded. With this many runs over several operating conditions, it is reasonable to expect a few non-normal process conditions and/or a few periods of poor particulate CEMS performance.

- It is reasonable to look for a three- or four-fold variation in the range of particulate concentrations in a good correlation test. For such a narrow range of data as seen for the Lilly tests, an evaluation of the correlation coefficient “r” is useless without any zero points. If zero points are not added, these data are wasted. But when zero points are added, the correlation curves are plausible and there is no time-dependency among the three correlation curves.

- For a data set he evaluated with approximately 45 Method 5i- measured points and 9 (20% of 45) zero points, “r” values were 0.91 and 0.85 for the Sigrist and ESA, respectively. Also, the “r” between the Sigrist and ESA was 0.85. These “r” values are very reasonable.

- Now focus on the paired Method 5i data. If four zero points are added to the original 53 data points, “r” = 0.9. Without the four zero points, “r” = 0.64. If the runs with relative standard deviations (RSDs) > 30% are excluded , “r” = 0.9. When the four zero points are added, “r” = 0.99.

According to Dr. Jockel, zero point correlation tests are standard requirements in Germany (see VDI 3950, Calibration of Automatic Emission Measuring Instruments) and are used in obtaining up to 20% of the correlation data. Furthermore, zero point correlation tests: (1) Represent relatively cost-effective and comparatively trouble-free data points; (2) Serve as a standard requirement on all types of gaseous CEMS, not just for particulate; and (3) Improve the scientific basis of the reference method and particulate CEMS correlation.

Conference Call with TÜV - Dr. Jockel, July 16, 1998

Five main issues were discussed.

1. *Cement Kilns in Germany*

There are 15 to 20 cement plants in Germany. Each plant typically has two to 3 kilns per location. All plants are equipped with an ESP, except the one with a baghouse. All burn hazardous waste and all comply with particulate standards.

2. *Are Cement Plants in Germany using Particulate CEMS for compliance? What types are they using?*

All cement plants in Germany use particulate CEMS for compliance with their particulate limits. In fact, Germany's work to establish particulate CEMS as a compliance tool started over 25 years ago with testing at a cement plant. Dr. Jockel sent a journal article documenting the tests (Buhne, 1972).

Nearly all cement plants in Germany use "Extinction Meters", that is what US cement industry calls "European-style opacity meters." This is somewhat of a misnomer, though, since they are really particulate CEMS, that is, they are calibrated to and being used to comply with a particulate -- not an opacity -- standard. Extinction meters are operationally the same as opacity monitors, except their output is converted into units of extinction. Extinction units are used because they have much greater sensitivity in the low measurement range of the instrument and exhibit a linear relationship with particulate concentration in CEMS correlations.

Extinction (EXT) is defined as:

$$EXT = \ln 1/(1-OP), \text{ where Opacity} = OP$$

Extinction meters are typically used on facilities with particulate concentrations from 15 to 100 mg/m^3. Extinction meters are marketed by Sick Optic and Durag. A few cement kilns in Germany use light-scattering particulate CEMS. These plants have particulate emissions around 1, 2, or 5 mg/m^3 on a 5 m duct.

3. What are the typical penalties associated with an "Exceedance" in Germany?

CEMS outputs (including particulate CEMS) are directly connected to the local authorities by telephone line (Northrhine Westphalia, for example). Emissions data (showing compliance with the daily and 30-minute requirements) are uploaded to the local authorities every day.

Violations are dealt with in what we in English law would term the "criminal" as compared to the "civil" process. If an exceedance occurs, the facility must write the local authorities within three days to explain the cause of the exceedance. Normally, exceedances are dealt with by first giving a "warning". In the most lenient case, this can happen as many as 5 to 10 times in a few years. This means that two to 3 exceedances in a given year are not dealt with harshly. In our system, this can be likened to the district attorney issuing a warning in writing stating that if the behavior continued, the state will pursue an indictment.

If the exceedance is excessive or recurring, then they "indict" the Plant Manager, a private citizen, and if convicted, fine that person 5 to 10,000 DM ($3 to $5.5k) per exceedance. The company is not held accountable. If after being fined violations still occur, the Plant Manager will be jailed. The fact that people, not companies, are held accountable and that people do go to jail for what we would term simple emissions violations means that the initial, gentle treatment of "infrequent offenders" is different, but comparable, to our situation in the US.

4. Based on TÜV's experience, what Particulate CEMS performance do they expect US Cement Kilns can achieve relative to the data acceptance criteria in PS11?

In comparison to an incinerator, doing a correlation at a cement kiln is relatively easy. This is because it is easy to vary emissions from an ESP, the stack is dry (no water droplets), and good repeatability of method measurements is possible over a wide range of PM concentration. Using either an in-stack (similar to Method 17) or out-of-stack methods (similar to Method 5) Dr. Jockel expects it would be relatively easy for a cement kiln to meet our proposed PS11 acceptance criteria for correlation coefficient, confidence interval, and tolerance interval. If condensible salts are an issue, in-stack methods should be used.

5. What emissions (on both 7% O_2 and dry basis) are German Cement Kilns emitting?

While national standards are in place for industrial processes, hazardous waste, municipal waste, etc., individual limits vary from plant-to-plant. The particulate emissions limit for cement kilns is (TI Air 1986) 50 mg/m^3 on a daily, block average; 100 mg/m^3 on a half-hourly block average, with no more than 97% of the half hour averages exceeding 60 mg/m^3. All are corrected to the European dry, standard conditions (dry, 11% O_2, 0°C)

The "Mixing Rule" affects the emissions limit by establishing the limit as a time-weighted average of various national standards. For example, if the cement kiln burns 80% coal and 20% hazardous waste and the particulate emissions (standards) while burning coal are 50 and the hazardous waste standard is 10, then the D/F limit for the facility would be 42 (50x0.8 + 10x0.2). This results in D/F limits which are typical (or slightly less than) those in EPA's proposed rules for cement kilns. Limits are also increased to account for measurement variability.

Typical particulate emissions at some German cement kilns do vary considerably, however, emissions ranges from 10 to 75 mg/ACM with 50 mg/ACM are expected.

Other Information Obtained from TÜV

Other discussions with Dr. Jockel indicate that most German incinerators normally have no problems operating at particulate levels less than 14 mg/dscm. In fact, recent advances in emission control practices and emission regulations there has created a need for a more sensitive reference method and a particulate CEMS able to accurately measure particulate levels less than 1 mg/dscm. In 1997 TÜV certified a particulate CEMS manufactured by Sigrist at a waste incinerators normal operation and emissions of less than 0.10 mg/dscm (TÜV-Rheinland, 1997).

They further note that particulate CEMS have not only been used for monitoring compliance, but also used as an effective means for achieving compliance. Just as CO and HC CEMS have become the common tool for maintaining optimum combustion conditions, particulate CEMS are likewise used as a tool to better define what process and APC conditions affect particulate emissions and how to reduce emissions. Facilities are given about 3 years to use their particulate CEMS as a means for evaluating their APCD performance and achieving compliance. The particulate CEMS also served as a check on the status and progress of their efforts and showed which operating styles were the most emission-effective. And likewise, APC vendors have benefitted from the new level of information produced by particulate CEMS. Apparently, this approach with using particulate CEMS is so effective that it has lead to dramatic improvement in emission control practices, as evidenced by achieving particulate emissions levels of less than 1 mg/dscm.

Over the past 10 to 15 years, most affected facilities in Germany have selected one of the light scattering monitors. This decision was made despite: (1) the sensitivity of optical devices to changes in particulate properties, such as size, refractive index, and density; and (2) the relationship between light scattering response and particulate concentration varies from plant to plant. Reportedly, light scattering was the method of choice because of their relative simplicity and reliability. Also many facilities operated in the sub-10 mg/m^3 level in which variations in particulate properties is minimal.